Nutrient Management Planning on Virginia Livestock Farms: Impacts and Opportunities for Improvement

by

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(ABSTRACT)

This study provides an environmental and economic analysis of the ability to reduce potential nitrogen loadings to water bodies through the implementation of nutrient management plans on livestock farms. Study results indicate that nutrient management plans do result in significant reductions while maintaining or increasing farm income. Nutrient management plans on the four case farms reduced mean nitrogen losses by 23 to 45 percent per acre while increasing net farm income from $395 to $7,249.

While reducing excess nitrogen applications with the implementation of nutrient management plans achieved significant reductions in potential nitrogen losses, further reductions may be achieved through farm level planning. After achieving initial reductions through the elimination of excessive nutrient applications, variation in application rates of organic and inorganic fertilizers across soils may become important in achieving further reductions in nitrogen loss. Study results suggest that it may be beneficial to apply higher rates of manure on soils and slopes less susceptible to nitrogen losses in order to reduce applications elsewhere. Increased nutrient losses on such fields may be more than offset by reductions on soils more susceptible to nutrient losses. Linear programming results for the Shenandoah Valley Dairy show that nitrogen losses could be reduced up to 44 percent below pre-plan losses with no impact on farm net economic returns. However, if nitrogen loss restrictions were instituted beyond this level, the impact on farm income increases significantly. After-plan nitrogen losses can reduced up to 52 percent, but farm returns decrease by 56 percent.

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Chapter 1: Introduction

Problem Statement

Over the last decade, as point sources of pollution have been addressed, nonpoint sources have become responsible for a larger share of surface and groundwater quality problems (Sharpley and Meyer). The term 'nonpoint source' pollution encompasses numerous sources of pollutants including urban runoff, septic tanks, lawns, and agriculture. Of these sources, agriculture is the largest contributor of nonpoint source pollution throughout the nation (Galeta et al.; Mitchell).

Modern agriculture has developed with a large dependence on chemicals, including nitrogen fertilizers (National Research Council). While nitrogen is necessary to achieve optimal plant growth, agricultural production inevitably generates a certain amount of residual products, including nitrogen, that can become pollutants. Nitrogen discharges from cropland are becoming increasingly associated with surface and ground water pollution problems. Nitrogen can enter the soil in several ways: 1) fixation by some plants, 2) application of fertilizers, 3) precipitation, 4) decay of plant residues, and 5) application of animal manures. Nitrogen that is not absorbed by the plant may be lost from the system through volatilization, denitrification, runoff, erosion, or percolation. The loss of nutrients from agriculture may ultimately reach rivers, lakes, or groundwater (Hanley).

When nitrogen in water bodies reaches excessive levels, it can result in both health and environmental problems. Nitrates in groundwater, such as wells, are associated with health problems such as methemoglobinemia or 'blue baby syndrome', an illness in which nitrates impair the ability of an infant's blood to carry oxygen (Crutchfield, Hansen, and Ribaudo). According to the Environmental Protection Agency, over half the wells in the United States contain nitrates, with approximately 1.2 percent of community wells and 2.4 percent of rural wells having nitrates above the 10 mg kg^{-1} (10 PPM) maximum contaminant level established by the EPA to protect human health (Galeta et al.) Nutrients from agriculture are also a significant factor in the continued eutrophication of lakes and estuaries in many areas of the country, including Lake Champlain, the Great Lakes, the Chesapeake Bay, and the San Francisco Bay (US EPA; McSweeney and Shortle; National Research Council). In the Chesapeake Bay, nutrient enrichment is one of three major water quality problems (US EPA). The Interstate Commission of the Potomac River Basin estimates that agriculture accounts for 39 percent of the nitrogen and 50 percent of the phosphorus entering the Bay (The Interstate Commission of the Potomac River Basin).

As a result of the large contribution of agriculture to the eutrophication of the Chesapeake Bay, a major target of water quality protection programs is agriculture. However, due to the difficulty in monitoring and enforcement of agricultural pollution programs at both the state and national level have traditionally been voluntary. In Virginia, one of the major emphases in the struggle to control pollution resulting from agricultural activities is the adoption of conservation practices designed to better manage the use of inorganic and organic fertilizers. These management practices are implemented in the form of a nutrient management plan. According to the National Research Council, increasing nutrient use efficiencies in farming systems is one of four broad opportunities holding the most promise of preventing soil degradation and water pollution while sustaining a profitable agricultural sector. Nutrient management planning is one of six major emphases of nonpoint source pollution programs in Virginia (Virginia Department of Conservation and Recreation, 1989). Although incentives may be involved, farmers usually agree voluntarily to follow the management practices laid out in the nutrient management plan. The practices outlined in the plan are designed not only to reduce water runoff and soil erosion but also to control the loss of nutrients such as nitrogen and phosphorus.

Nutrient management plans can be particularly important on livestock farms where the application of animal residues in addition to commercial fertilizers increases the potential of a farm to contribute to pollution problems. Annually, livestock farms in the Untied States produce 7.5 million tons of nitrogen and 2.3 million tons of phosphorus in the form of animal wastes (Huang). Geographically concentrated animal agriculture is one of the major contributors to agricultural nitrates flowing into the Bay (Parsons; Young et al.). A study by Legg et al. in southeastern Minnesota and a study by Bosch et al. in the Chesapeake Bay Area of Virginia have both found that livestock farms may contribute disproportionately to nitrogen losses. Livestock farms produce large amounts of manure, which is traditionally disposed of in the most economical manner through application of the manure to fields closest to the animal housing center (Parsons). This practice limits manure disposal costs and reduces the risk of limiting crop yields on those fields due to nutrient deficiencies (Babcock; Bitzer and Sims; Young et al.; Parsons). However, applying manure in this fashion concentrates nutrients in a limited area and may increase the likelihood of nutrient losses to water supplies.

While nutrient management planning is currently one of the more emphasized nonpoint source programs in Virginia, evaluation of the on-farm environmental and economic impacts is lacking. It is a general assumption underlying the development of these plans that reducing nutrient application rates or altering application and storage practices will lead to reduced nutrient losses while not decreasing profitability. However, it is unknown what level of reduction in potential nutrient losses to surface and groundwater results from compliance with the plans. "While current understanding of the effect of farming systems on soil and water quality is generally sufficient to identify the best available production practices or management systems; it is not, however, sufficient for making quantitative estimates of how much soil and water quality will improve as a result of the use of alternative practices or management methods" (National Research Council). As a result, the environmental and economic tradeoffs implied by voluntary nutrient management plans are uncertain.

As federal, state, and local policymakers have struggled to stretch sometimes shrinking budgets to keep up with the increasing list of items on the environmental agenda, the need for refined targeting has been made more urgent (National Research Council). According to the National Resource Council, the decision to target programs at particular regions or enterprises should ideally be based on 1) articulation of national or state goals for soil and water quality; 2) identification of regions where the benefits from achieving the goals per dollar invested are greatest; 3) identification of the linkages among farm practices, soil quality, and water quality; and 4) identification of, within targeted regions, those enterprises that contribute to the problem as well as their barriers to changing their farming systems (National Research Council).

As a result of the Chesapeake Bay nutrient enrichment problem, Virginia, Maryland, and Pennsylvania have set a reduction goal of forty percent for loadings of both nitrogen and phosphorus from controllable sources in the Bay. Also, the Bay states have already targeted general geographic areas that will be emphasized in the implementation of agricultural pollution control programs (US EPA). These areas have been targeted based on potential for contributing to pollution problems of the Bay. As a result of measures already taken, the Chesapeake Bay Program Phase II Watershed Model shows that phosphorus loads delivered to the bay in 1992 were 21 percent lower than loads delivered in 1985 while nitrogen loads were reduced by 5 percent. Although the amount of the reduction of phosphorus loadings is significant, little has been achieved in terms of nitrogen.

Although it is well known that farm characteristics are associated with the outcome of alternative management practices, knowledge about the linkages among farm practices, soil quality, and water quality is piecemeal. While great progress has been made, more specific information is needed on the effects of farm practices and crop management decisions on water quality (Bosch et al.). More information is also needed relating soils and cropping systems to regional water quality problems (Galeta et al.). It is unknown by policy implementors whether alternative management practices could achieve greater reductions in nutrient losses than those achieved currently or if reductions could be achieved at a lower cost.

Voluntary nonpoint source pollution control programs are preferred by many policymakers and most farmers, and will therefore likely remain an integral part of nonpoint source water quality protection programs in the foreseeable future (Pease and Bosch; Park and Sawyer). However, if voluntary programs prove unsuccessful in achieving the necessary reduction in nonpoint source pollution, alternative policies may be adopted (Pease and Bosch). Therefore, it would be to the benefit of both producers and policymakers to achieve the highest level of reduction for a given expenditure. However, due to the complexity of the systems involved in the transport of pollutants from nonpoint sources to water bodies, it would be extremely costly and time consuming for policy implementors to construct models for individual farms in order to determine which practice has the most potential for reducing nutrient losses. By beginning to examine the possibilities for improving nutrient management planning, this thesis will provide information which will help policymakers and implementors to better target efforts within previously identified critical areas in order to achieve pollution reduction goals more cost effectively.

Previous Research

Ex-post evaluation of nutrient application rates has led to the observation that producers often apply more fertilizer than is needed to achieve optimal crop yields (Babcock). In addition, agricultural watersheds with the largest nitrate losses are often associated with nitrogen applications in excess of estimated crop nitrogen removal. Parsons, Pease, and Bosch estimated potential nitrogen losses from 120 sites in the Northern Neck and Shenandoah Valley regions of Virginia and found that nitrogen losses from sites receiving excess nitrogen applications were three times as high as the losses occurring at other sites (Parsons, Pease, and Bosch). As a result of the high nutrient losses associated with excess fertilizer applications, numerous studies have found the reduction of nitrogen inputs to be one of the most obvious practices in reducing potential nitrogen losses from cropland (Crowder and Young, Crowder et al.).

To better match fertilizer applications to crop needs and therefore minimize potential losses of excess nitrogen to the environment, the contribution to crop needs by on-farm nutrient sources must be considered. Organic nitrogen sources, such as manure, have been used successfully as a source of nutrients for centuries (Sims). While providing crop nutrients, manure applications also improve soil structure and tilth, and increase the soil's ability to hold water and nutrients (National Research Council). However, manure nutrient content is not nearly as consistent as that of commercial fertilizers. Plant available nutrients from manure applications will vary with manure type and handling and storage practices. While estimation of precise nutrient content and plant availability can be difficult, several studies have shown that crediting manure nutrients can result in significant reductions in commercial fertilizer application and loss of nitrogen.

One such study by Parsons evaluated dairy and dairy/poultry farms in Rockingham County, Virginia. In this study the Erosion Productivity Impact Calculator (EPIC), was used to simulate the impact of nutrient application constraints on yields and potential nutrient losses. One alternative examined in this study is the restriction of nitrogen fertilizer applications, including manure nitrogen, so as not to exceed agronomic recommendations. Agronomic recommendations used in the study are based on the Virginia Agronomic Land Use Evaluation System (VALUES). The restriction on fertilizer applications resulted in a decrease in farm level nitrogen losses of approximately 30 percent and phosphorus of approximately 6 percent below those resulting from current fertilizer applications. Limiting nitrogen applications in this manner increased farm income slightly for all farms examined because nitrogen content of manure was not previously considered in planning for plant needs.

While limiting total plant available nitrogen applications to crop needs may appear to be a simple process for achieving nutrient loss reductions, it can be difficult to achieve. The difficulty results from the necessity of estimating the amount of nitrogen fertilizer needed before the crop is grown. At the time of fertilizer application, weather and other factors that may affect nitrogen availability and plant growth throughout the season are unknown. Therefore expected yields must be estimated based on incomplete information in order to determine nutrient needs of the crop.

As a result of fluctuations in growing conditions and therefore yields from year to year, nutrient requirements will vary. If nitrogen applications are based on expected yields, it is likely that in some years too little nitrogen will be applied to achieve optimal yields, while in others, too much will be applied. This inherent uncertainty regarding crop yields may result in farmers applying excess nitrogen to crops. In fact, results of the study by Babcock suggest that uncertainty concerning weather and soil nitrogen can induce up to a 36 percent increase in optimal nitrogen applications compared to when a producer faces no uncertainty . Another study by Babcock and Blackmer estimated that soil nitrate uncertainty alone can increase optimal nitrogen applications by up to 38 percent.

The problem of excess nitrogen applications may also be compounded by poor timing of fertilizer application. Nitrogen applied before it is needed by the crop is subject to loss through leaching and subsurface flow. Therefore, if nitrogen is applied before it is needed by a crop, a higher application may be necessary to achieve yield goals. The efficiency of nitrogen use by plants can be increased by synchronizing applications with periods of crop growth (National Research Council). By increasing efficiency of crop use, it may be possible to reduce fertilizer applications without reducing yield.

One way to better time nitrogen applications with plant growth is to split nitrogen applications. While splitting nitrogen applications may result in higher fertilizer application costs, this cost may be at least partially offset by reductions in fertilizer application rates. By applying fertilizer closer to the time of maximum crop uptake, less fertilizer may be needed to achieve desired yields. Split applications can also allow for improved estimation of crop needs through the use of tissue tests or nitrate quick tests (a presidedress nitrogen test) during the growing season. Splitting of nitrogen applications allows for the adjustment of fertilizer application recommendations after planting through the use of test results. These tests may allow for more accurate nitrogen applications by reducing uncertainty about plant available nitrogen already present in the soil. Several studies have found that the reduction of uncertainty can be particularly important when manures or legumes are used to provide nitrogen for crops.

While it may be possible to achieve the desired reductions in nitrogen loss through the use of alternative management practices, the studies reviewed suggest that the magnitude of the reductions achieved by nutrient management are affected by not only specific management practices but also by the physical characteristics of the farm. Wide variations are seen in nitrate losses and the impacts of alternative management practices on those losses not only across cropping systems, but also across soil type (Galeta et. al; Hamlet and Epp). Also, a number of factors, including impact on yields and policy type will affect the loss of profits farmers experience from adoption of practices designed to reduce water quality damage (Bosch and Wolfe). In the long term, it is unclear whether improvements in nitrogen management alone will result in sufficient reduction in nitrogen loadings to achieve water quality protection goals (National Research Council).

In Virginia, one thousand nutrient management plans have already been developed for 240,000 acres of cropland (Perkinson). Determining the impacts of nutrient management plans on nutrient loss and farm income requires identifying those participating in the program, estimating before and after nutrient management practices and the resulting changes in nutrient losses. Without knowledge concerning the degree of impact nutrient management plans have had on nitrogen losses, it is also impossible to determine if losses could be reduced further. However, while it is difficult to determine what impact alternative management practices laid out in nutrient management plans have had on nitrogen losses, previous studies allow for the identification of practices that are likely to have been the most successful in achieving nitrogen loss reductions (Crowder and Young; Crowder et al.; Diebel; Hall and Risser; Maiga; Norris and Shabman; Parsons).

Clearly, the most important step in achieving a reduction in potential nitrogen losses is to reduce the amount of excess nitrogen present in the soil system. Although the timing and method of application clearly have an impact on potential losses, the amount of the application seems to be more significant (Parsons, Pease, and Bosch). Once the application rate is more in harmony with plant needs, other management practices become important in achieving further reductions. The use of cover crops appears to be very successful in helping to stabilize nitrogen already present in the soil system. Also, the use of split fertilizer applications can allow for application of fertilizers closer to the time of plant need and also for the use of soil and tissue tests after plant growth has begun. The use of these tests during the growing season can allow for a more accurate estimation of nutrient availability and therefore refinement of fertilizer application rates. The combination of change in timing of applications and possible reductions in application rates may greatly reduce the potential for nitrogen losses from the soil system.

While some studies have examined the varying impacts of nutrient management practices across soils, most of the studies reviewed examine nitrogen loss reductions when alternative management practices are applied to the farm as a whole. One area that has been overlooked is the possibility of reducing farm level nutrient losses by targeting alternative management practices within individual farms to specific fields or soils. While crop management practices may have significant impacts on nutrient losses, the variations in losses across soil types may become more important when engaging in nutrient management planning at the farm (rather than field) level. For example, it may be possible to reduce farm level nitrogen losses significantly through alternative routing of manure and commercial fertilizer applications within a farm based on information about soils and slopes. Significant reductions in total nitrogen losses may be achieved through the higher application of nutrients (particularly from manure) on those soils and slopes less susceptible to nutrient losses. Increased nutrient losses on such fields may be more than offset by reductions on soils more susceptible to nutrient losses and therefore be a means to achieve the same level of reductions at a lower cost or to achieve greater reductions.

Objectives

This study will focus on evaluation of management practices designed to reduce the loss of nitrogen from livestock farms in Virginia, variation of results across soils, and opportunities for further reducing nitrogen losses without imposing additional costs on the producer. The information will be used to derive hypotheses, which can be tested in later studies, about the associations between livestock farm characteristics and opportunities for reducing nitrogen loss. In doing so, this study will explore the ability to better target alternative management practices within farms by examining the relationship of soil type and slope to the impacts of management practices on nitrogen losses and farm profitability. Information concerning the linkages of farm characteristics and potential nitrogen loss reduction will be used to determine the cost of further reductions in nitrogen losses on livestock farms. This study has three specific objectives:

1. To analyze the effects of nutrient management practices on farm net returns and nitrogen loss for four livestock farms in Virginia.

2. To examine the effects of soil type and slope on the costs of achieving nitrogen loss reductions.

3. To examine methods for improving nutrient management planning in order to either achieve greater nitrogen loss reductions than those currently achieved without decreasing farm profits or achieve current reductions at a lower cost.

Methods

First, a literature review is conducted. The purpose of the literature review is to examine nitrogen cycle and mass balance considerations necessary in understanding options for improving nitrogen management. In addition, selected studies will be reviewed to determine what is known concerning the impact of alternative management practices on nitrogen losses and farm net returns.

Next, case farms are selected and data necessary to determining the impact of nutrient management planning on nitrogen losses and farm income are collected. The case farms are chosen through consultation with nutrient management specialists and project managers to represent a cross section of Virginia livestock producers. The selected farms have nutrient management plans with sufficient information to analyze nutrient losses and economic performance before and after the implementation of the plan. Necessary data are collected through evaluation of the nutrient management plan, consultation with the appropriate nutrient management specialist, and interview with the producer. The impact of selected management practices designed to control the loss of nitrogen is modeled using the Erosion Productivity Impact Calculator (EPIC). EPIC is a USDA-developed physical crop growth model which simulates crop growth as well as erosion and nutrient loss on a daily time step. The simulations utilize data on soil characteristics, crop rotation, management practices, and weather parameters (Williams et al.) EPIC estimates not only nitrogen uptake by plants but also denitrification, volatilization, and the loss of nitrates in runoff and percolation. In using this model, impacts of nutrient management practices on nutrient losses at the edge of the field and the edge of the root zone can be estimated. The model has been validated in numerous studies in which EPIC results have been found to be consistent with field measurements of nitrogen losses and crop yields (Jones et al. 1984, 1985; Smith et al.; Parsons, Pease, and Martens).

Once the modeling of management practices is completed, partial budgets are constructed to examine the change in farm profit resulting from the implementation of the identified management practices on selected farms. The development and results of EPIC simulations and partial budgets will be discussed in Chapter 3.

Finally, mathematical programming is used to examine the possibilities for improving nutrient management planning on one of the case farms. A profit maximization framework is used which incorporates numerous alternative nutrient management practices. Alternatives include the use of split applications, use of animal wastes, and the use of cover crops. Each of these practices is examined on various soils present on the farm. This allows for a more in depth analysis of how variation in farm characteristics within a farm and alternative nutrient management activities may affect the potential to reduce nitrogen losses at a lower cost than is currently being achieved. The model contains nutrient losses and crop yields estimated by EPIC. The development of this model is discussed in Chapter 4 while the results are presented in Chapter 5. A summary of the thesis and conclusions of the study are presented in Chapter 6.

Chapter 2: Literature Review

Introduction

Modern agriculture has developed with a large dependence on petro-chemicals used for pest control and fertilization (National Research Council). In the Chesapeake Bay, agriculture is the largest controllable nonpoint source of pollution (Dept. of Environmental Quality). In controlling nonpoint sources, Virginia has placed emphasis on voluntary practices, such as those contained in nutrient management plans, which can lead to the greatest reduction of nutrients in ground and surface waters (Perkinson). In 1993, the Department of Environmental Quality reported that nonpoint source nutrient loss reductions will continue to be addressed through the implementation of the Chesapeake Bay Preservation Act, agricultural cost-share, nutrient management, and farm plan programs.

While nitrogen is one of the most important plant nutrients in a cropping system, it is also one of the most mobile compounds. Nitrogen enters and leaves the soil through many different pathways. The same processes that make nitrogen available for plant use also make nitrogen susceptible to loss from the system.

This chapter will start with a discussion of the nitrogen cycle and mass balance considerations necessary in understanding the options for improving management of nitrogen in farming systems in order to minimize environmental impacts. Next, the results of various studies concerning the potential opportunities for reducing nitrogen losses from agricultural sources will be summarized. Finally, implications of these studies concerning the scope of the empirical model to be used in evaluating opportunities for improving nutrient management planning will be addressed.

Sources of Nitrogen

While nitrogen is necessary to achieve optimal crop yields, excess nitrogen applied to crops and pasture can contribute to surface and groundwater quality problems. Nitrogen can enter the soil in several ways: 1) fixation by some plants, 2) application of fertilizers, 3) precipitation, 4) decay of plant residues, and 5) application of animal manures.

Livestock farmers generally add nitrogen to cropland through the application of commercial fertilizers and animal manures. Most commercial nitrogen fertilizers, which are formed from ammonia or ammonia derivatives, are readily available to plants as ammonia or ammonium. Manure contains ammonia and organic nitrogen in addition to other nutrients and organic matter. Manure improves soil structure and tilth, and increases the soil's ability to hold water and nutrients (National Research Council).

Nitrogen Loss Pathways

Once nitrogen is present in the soil, in its related forms, a series of biochemical processes, referred to as the nitrogen cycle, transform nitrogen into forms that are available for plant utilization.

Plants absorb nitrogen in the form of ammonia (NH_3), ammonium (NH_4), and nitrate (NO_3). These compounds are formed through the processes of nitrogen fixation, mineralization, and nitrification respectively. Nitrogen that is not absorbed by the plant may potentially be lost from the soil system.

Nitrogen can be lost from the soil environment through erosion, runoff, leaching (including percolation and subsurface flow), denitrification, and volatilization. Ammonia (NH_3) volatilization and denitrification of nitrate to nitrogen (N_2) and nitrous oxides (N_2O) are gaseous losses to the atmosphere. These gases are among those that contribute to the so-called greenhouse effect and may also affect the protective layer of the ozone (National Research Council). Nitrogen is also lost attached to eroded soil particles, through runoff, and through leaching. Nitrogen lost through these processes may ultimately contribute to surface and groundwater pollution problems.

The amount of nitrogen loss through erosion is related to the amount of soil loss as well as the concentration of nitrogen in the soil. Nitrogen loss through erosion is in the form of ammonium in addition to the organic nitrogen attached to soil particles (National Research Council). Runoff and leaching losses occur when water soluble nitrogen, nitrate, is lost with water movement through the soil environment. Nitrate is the form of nitrogen most commonly associated with water quality problems (National Research Council). While ammonium is relatively immobile in the soil, it is readily converted into nitrate.

Nitrogen losses will vary according to the rate of fertilizer application, timing of applications, plant uptake, source of nitrogen, weather, and soil characteristics (Scharf and Alley). For example, soils with high water holding capacities can accumulate significant amounts of water before percolation, and therefore leaching, occurs. Therefore, a soil with high water holding capacity may be less susceptible to leaching losses than a soil with low water holding capacity.

Nitrogen Mass Balance

Applied to agriculture, the term nitrogen mass balance refers to the accounting of all inputs and outputs of nitrogen in the soil-crop system. Nitrogen can enter and leave the soil through numerous processes. Nitrogen is absorbed by crops and can be removed with the harvested portion of the crop or can remain in the soil in the roots or crop residues. Nitrogen left in the soil system after plant use is a potential source of agricultural nonpoint source pollution. The problem of excess nitrogen (nitrogen not taken up in crop production) may be magnified on livestock farms as a result of the high volume of animal wastes often produced.

A study by Legg, Fletcher, and Easter in southeastern Minnesota estimating nitrogen sources and uses on four individual farms indicated that nitrogen balance is highly dependent on the type of farm. Results suggest that livestock farms, particularly dairy, may contribute disproportionately to excess nitrogen applications to cropland. While the continuous corn farm exhibited a close balance between crop needs and fertilizer applications, the beef farms had excesses of 20 to 60 pounds per acre, and the dairy had 130 pounds per acre of excess nitrogen applications. Part of the difference between livestock farms may be attributed to manure collection practices of the producer (Legg, Fletcher, and Easter). On the dairy farm, 90 percent of manure production was collected. On the beef farms, much of the manure produced fell on pasture and was uncollected.

A study by Bosch, Pease, Batie, and Shanholtz examining the crop selection, tillage practices, and chemical and nutrient applications in the Northern Neck and Shenandoah Valley Regions of

Virginia contained in the Chesapeake Bay Watershed found that excess nutrient applications (defined in this study as application above agronomic crop recommendations) were significantly higher on sites where manure was applied than on sites without manure applications. In this study, poultry farms were found to have significantly more excess nitrogen and phosphorus applied to the land than any other farms.

In another study, Parsons, Pease, and Bosch estimate nitrogen losses from 120 of the sites examined by Bosch et al.(ibid.). Nitrogen losses were estimated through the use of EPIC, a soil erosion / crop growth simulation model. Results of the study suggest significant differences between nitrogen losses on sites receiving excess nitrogen in comparison to sites receiving nitrogen below recommended amounts. Nitrogen losses from these sites were found to be three times as high as the losses occurring at other sites (Parsons, Pease, and Bosch).

Nutrient Management Plans[1]

Nutrient management planning attempts to reduce losses of nutrients from cropland through the better management of fertilizers, including animal manures, applied to agricultural land. Nutrient management plans are written plans indicating how major plant nutrients are to be managed to match nutrient application rates and timing of applications to correspond with crop uptake in order to minimize the environmental impacts associated with nutrient use (Perkinson). Nutrient management specialists work with farmers in developing a written plan indicating how nitrogen, phosphorus, and potassium will be managed annually based on expected crop production while considering the protection of water quality. Crop nutrient requirements are estimated through the use of soil tests, soil productivity potential, and farmer yield history. Estimated crop nutrient needs may be adjusted during the growing season based on soil or tissue tests.

In meeting crop requirements, on-farm sources of nutrients are utilized first. These sources include both animal manures and legumes. Any remaining needs are met through the use of commercial fertilizers. Fertilizer applications are timed as closely as possible to the time of the plant's greatest nutrient needs by encouraging the use of split fertilizer applications in addition to the use of soil tests and tissue tests to make a final determination of application rates.

Methods to Reduce Nutrient Losses

"Management practices for organic N sources have two fundamental goals: to optimize plant N recovery and to minimize pollution from N and other waste constituents" (Sims). In order to achieve these goals, many methods may be used to reduce excess nitrogen (nitrogen not taken up in crop production) in the cropping system. In order to limit excess nitrogen, it is necessary to determine crop nutrient requirements based not only on potential yields, but also on availability of on-farm sources of nitrogen and timing of fertilizer applications. While the crediting of on-farm sources and better timing of applications can result in significant reductions in nitrogen losses from agricultural sources, nitrogen loss will also be impacted by the amount of soil loss occurring at a site. In addition, the ability to reduce nitrogen losses from a farm and the costs of those reductions will depend at least partially on farm physical and economic characteristics.

[1] This section is drawn from Perkinson (1994).

Crop nutrient requirements

Ex-post evaluation of nutrient application rates has led to the observation that producers often apply more fertilizer than is needed to achieve optimal yields (Babcock). In addition, agricultural watersheds with the largest nitrate losses are often associated with excess nitrogen inputs. Therefore, numerous studies have found the reduction of nitrogen inputs to be one of the most obvious practices in reducing potential nitrogen losses from cropland (Crowder and Young, Crowder et al.).

Diebel incorporated a chemical mass-balance approach into a mathematical programming model (through the use of CREAMS) to examine the opportunities for reducing nitrogen losses through the implementation of low input agriculture. The study was conducted in the predominantly grain producing area of Richmond county, Virginia. Low input agriculture is defined as any production system in which pesticides or manufactured nitrogen fertilizer are applied at or below Extension Service recommended rates. The results of this study suggest that more closely matching input use to crop needs reduces the potential of cropland to contribute to the contamination of ground and surface water. Results also suggest that the use of low-input practices may be profitable for producers. In the evaluation of several alternative nutrient management scenarios, the crediting of nitrogen available from crop residues in determining crop nutrient needs consistently reduced nitrogen loss and increased total net return for the county when other management practices were held constant.

Hall and Risser conducted a field study of the impact of nutrient management on nitrogen load in groundwater discharged from a 55-acre site in Lancaster county, Pennsylvania over a period of five years. Due to the existence of terraces and grass-covered waterways in addition to the presence of permeable soils, the loss of nitrogen with runoff constituted less than one percent of total nitrogen outputs and was therefore not a focus of the study. Total nitrogen outputs in this study are defined to include nitrogen removed with crops, through leaching to groundwater, through volatilization, and in runoff. After implementation of a nutrient management plan limiting commercial fertilizer and manure application to crop nutrient requirements, median nitrate concentrations in groundwater (as measured in samples collected from shallow wells) decreased from 8 to 32 percent below levels measured before nutrient management. These reductions in losses correspond to reductions in nitrogen applications of 39 to 67 percent respectively in areas defined to be upgradient of these wells. These results show that limiting nutrient applications to crop needs can significantly reduce nitrogen losses below those occurring when fertilizers are applied in excess of crop needs. However, the reduction in losses is less than the reduction in application.

Balancing nitrogen entering and leaving the soil-crop system can be achieved by more closely matching nitrogen applications to crop requirements. Although this may sound like a straight forward goal, it can be difficult to achieve. The difficulty results from the necessity of estimating the amount of nitrogen fertilizer to be applied before the crop is grown. At the time of fertilizer application, weather and other factors that may affect nitrogen availability and plant growth throughout the season are unknown. Therefore expected yield must be estimated based on incomplete information in order to determine nutrient needs of the crop. According to the National Research Council, the most reliable way to set realistic yield goals is to utilize information on historical yields achieved on a field-by-field basis. Preferably, yields goals should also be determined on a soil-by-soil basis.

In developing nutrient management plans, nutrient management specialists make use of the farmer's historic yields. However, since weather in a given year is unknown, future yield expectations are only estimates. As a result of fluctuations in growing conditions and therefore yields from year to year, nutrient requirements will vary. If nitrogen applications are based on expected yields, it is likely that in some years too little nitrogen will be applied to achieve optimal yields, while in others, too much will be applied. This inherent uncertainty in crop production may lead farmers to apply excess nitrogen to crops, that is, more nitrogen than is removed by the crop. By applying excess nutrients, producers reduce the risk of limiting crop growth due to a shortage of nitrogen. Young et al. argue that it is economically rational for farmers to over apply manure nutrients for several reasons: 1) the additional income generated from adding a cow exceeds the additional expense of disposing of the extra manure and 2) experimental results indicate a broad plateau over which yields do not decrease with excess nutrient applications.

Babcock examines the impact of uncertainty regarding weather and soil nitrate levels on 'optimal' nitrogen fertilizer application rates using a linear response and plateau (LRP) model representing crop response to nitrogen applications[2]. The functional form is appropriate if plant level production functions operate on a limiting nutrient concept (Babcock and Blackmer)[3]. The limiting nutrient concept means an increase in the most limiting input will increase yield until another input becomes the limiting factor. At that point, the original limiting factor will no longer affect yield. With the LRP function, the marginal product of nitrogen is not continuous at the concentration that achieves the plateau yield.   Below the plateau yield, the marginal product is a constant. After the plateau yield is achieved, the marginal product of nitrogen is zero. Since the plateau yield is governed by the most limiting factor, the plateau yield at which additional nitrogen applications will no longer have an impact on yield will vary from year to year. Therefore, an additional unit of nitrogen may or may not increase yield. Babcock illustrates that the level of nitrogen used under uncertainty (concerning the plateau yield) will be greater than the amount of nitrogen used under certainty when the marginal product of nitrogen (when nitrogen is limiting) is more than twice the price of nitrogen. Therefore, it may be profitable for risk neutral farmers to apply nitrogen for the good years. This is consistent with the observation that some U.S. producers tend to apply extra fertilizer 'just in case'. In fact, results of the study by Babcock suggest that uncertainty concerning weather and soil nitrogen can induce up to a 36 percent increase in optimal nitrogen applications compared to when a producer faces no uncertainty . Another study by Babcock and Blackmer estimates that soil nitrate uncertainty alone can increase optimal nitrogen applications up to 38 percent.

McSweeney and Shortle examined the fertilization problem on a mixed crop-livestock farm from the perspective of a risk-averse farmer facing manure nutrient uncertainty and uncertainty about the response of crop yields to fertilization.   The representative farm was based on dairy farm practices observed in Lancaster County, Pennsylvania. A safety-first approach was used to examine decision-making under uncertainty in comparison to risk-neutral profit maximization.   With no restrictions on fertilizer use, the producer operating under the safety-first framework applied nitrogen in excess of anticipated crop needs by 117 pounds per acre and expected net returns were 20 percent lower than under a profit-maximization framework.

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[2] Soil scientists Cate and Nelson first introduced the linear response and plateau model, which they argue is capable of capturing the essential information of yield response to nutrients such as nitrogen (Lanzer and Paris).

[3] A study by Perrin comparing the use of a quadratic function and the LRP function in determining optimal fertilizer application rates suggests that the LRP function will provide recommendations as valuable to farmers as those from the quadratic function.

The results of these studies suggest that the variability in crop yields due to changes in growing conditions can induce producers to apply higher nitrogen fertilizer to crops than would be needed to achieve profit maximizing yields. However, sites with excess nitrogen applications have significantly higher losses than sites in which nitrogen is applied at or below crop requirements (Parsons, Pease, and Bosch). Therefore, the variability of nitrogen requirements of crops is crucial in reducing nitrogen losses.

In using EPIC to simulate nitrogen losses from 120 survey sites in Rockingham County, Virginia, Parsons, Pease, and Bosch find that a significant amount of variation in nitrogen losses is explained by soil water capacity, soil slope, manure nitrogen applications, commercial nitrogen applications , and tillage. However, management practices such as fertilization rates were found to have a more significant impact on nitrogen losses than soils (Parsons, Pease, and Bosch). Sites receiving nitrogen applications in excess of crop needs had nitrogen losses three times greater than losses occurring at sites with nitrogen fertilizer applications at or below agronomic recommendations. Sites receiving manure applications received higher nitrogen applications than those without manure. This study indicates the importance of information concerning crop management practices, especially manure applications (Parsons, Pease, and Bosch).

On-farm sources of nitrogen and timing of fertilizer applications

To better match fertilizer applications to crop needs and therefore minimize potential losses of excess nitrogen to the environment, the contribution to crop needs by on-farm sources must be considered. Manures and legumes are two on-farm sources that can be used to add nitrogen and phosphorus to the soil system.

Symbiotic bacteria associated with leguminous crops such as alfalfa and clover can add substantial nitrogen to the soil by converting atmospheric nitrogen into a form that can be used directly by plants. While estimation of fixation by legumes can vary widely, crop rotations with legumes consistently produce yield benefits to succeeding crops with reduced inputs of nitrogen (National Research Council).

Organic nitrogen sources, such as manure, have been used successfully as a source of nutrients for centuries (Sims). While providing crop nutrients, manure applications also improve soil structure and tilth, and increase the soil's ability to hold water and nutrients (National Research Council). However, manure nutrient content is not nearly as consistent as that of commercial fertilizers. Plant available nutrients from manure applications will vary with manure type and handling and storage practices. While estimation of precise nutrient content and plant availability can be difficult, several studies have shown that crediting manure for some nutrient content can result in significant reductions in commercial fertilizer application and loss of nitrogen.

One such study is an evaluation of representative dairy and dairy/poultry farms in Rockingham County, Virginia conducted by Parsons. In this study, EPIC, the Erosion Productivity Impact Calculator, is used to simulate the impact of several alternatives on yields and potential nutrient losses. One alternative examined in this study is the restriction of nitrogen fertilizer applications, including manure nitrogen, so as not to exceed agronomic recommendations. Agronomic recommendations used in the study are based on The Virginia Agronomic Land Use Evaluation System (VALUES). The restriction on fertilizer applications results in a decrease in farm level nitrogen losses by approximately 30 percent and phosphorus losses by approximately 6 percent below those obtained under current fertilizer applications. Limiting nitrogen applications in this manner increases farm income slightly for all farms examined because nitrogen content of manure was not previously considered in planning for plant needs. In limiting fertilizer applications so as not to exceed phosphorus requirements of crops, Parsons finds that both nitrogen and phosphorus losses are reduced further below those achieved when fertilizer application is limited by only nitrogen requirements of the crop. However, limiting fertilizer applications in this manner does decrease farm income across all farms. The largest percentage reductions in nutrient losses occur on the 60 - cow dairy/poultry farm, the farm with the largest nitrogen and phosphorus losses per acre. Limiting fertilizer applications (including manure nutrients) so as not to exceed phosphorus requirements lowers net cash income on all dairy and dairy/poultry farms examined

One difficulty in using animal manures to meet crop nutrient needs is accurately determining the availability of nutrients in wastes to plants. The nutrient content of manure can be highly variable depending on animal species, feed rations, form, handling, and storage (National Research Council; Sims). However, while a high degree of variability is commonly observed in nitrogen content of wastes, certain organic wastes consistently have higher total nitrogen content than others. For example, poultry manure is generally higher in total nitrogen content than dairy wastes which in turn are generally higher in nitrogen content than beef wastes (Sims). While generalizations can be made concerning relative nutrient content of manures, the high variability in nutrient availability can have significant effects on nitrogen loadings to soils and crops. Uncertainty concerning nitrogen availability may also encourage farmers attempting to maximize economic returns to apply plant-available manure nitrogen at higher levels than crop requirements (Parsons, Pease, and Bosch; Babcock; Sims; National Research Council). The availability of nitrogen from organic wastes will be affected not only by the composition of the waste but also by the chemical and biological changes that occur following application to the soil (Sims). Processes that affect nitrogen availability include the volatilization of ammonia nitrogen, the loss of nitrate due to denitrification, the mineralization of organic nitrogen, and the immobilization of organic nitrogen.

While a producer may not have a direct impact on the chemical and biological processes affecting nutrient content of animal manures, nitrogen content and losses can be indirectly affected by manure management practices such as the method of application. Surface application of fertilizers, particularly manure, can result in large amounts of volatilization (National Research Council). Repeated studies have shown the immediate incorporation of manure is the most successful approach to significantly reducing volatilization losses (Sims). A reduction in volatilization may result in higher availability of nitrogen for plant use. However, if incorporation of manure adds tillage to a system when none was used before, it may increase erosion and surface and subsurface losses of nitrogen.

Parsons examines the incorporation of manure applied to fields where crops are not growing at the time of application. This practice was found to reduce volatilization losses by 5-7 percent while increasing surface and subsurface losses by 1-3 percent. This result suggests that while incorporation of manure may help reduce volatilization, it also increases potential for surface and groundwater pollution.

Further uncertainty about nutrient content of animal wastes results from the fact that a large portion of the nitrogen in manure is in organic form which only becomes available over time as it is mineralized (Sims). Mineralization is the transformation of organic forms of nitrogen to ammonium (NH4). Once mineralized, ammonium can then be nitrified, or converted into nitrite and then nitrate. As mineralization is controlled by soil microorganisms, temperature, moisture, aeration, and soil pH will influence the rate of transformation. Therefore mineralization is dependent on weather and soil conditions (Sims). Optimum conditions for mineralization have been broadly defined as a temperature range of 40-60˚C and a soil moisture content of 50-75 percent of soil water-holding capacity (Sims). Mineralization rates may vary due to variation in soil temperature, moisture, and weather. This variation will add to the uncertainty concerning plant available nitrogen content of manures.

While several studies have shown that soil type affects nitrogen availability from organic wastes, studies generally confirm the view that the differences between wastes is a larger influence . In fact, one of the most important properties that will affect mineralization is the carbon-to-nitrogen ratio (Sims). Organic wastes with low C:N ratios (low in carbon, high in nitrogen), such as poultry manures, can mineralize rapidly compared to wastes with high C:N ratios. Although mineralization rates will vary, the slow release of nitrogen may contribute to nitrogen needs of crops over several seasons. Therefore, calculating the amount of nitrogen provided by manure must include a calculation of residual nitrogen from applications in previous years.

Nitrogen applied before it is needed by the crop is also subject to loss through leaching and subsurface flow. Therefore, if nitrogen is applied before it is needed by a crop, a higher application may be needed to achieve yield goals due to the possible increased loss. The efficiency of nitrogen use by plants can be increased by synchronizing applications with periods of crop growth (National Research Council). By increasing efficiency of crop use, it may be possible to reduce fertilizer applications without reducing yield.

One way to better time nitrogen applications with plant growth is to split nitrogen applications. While splitting nitrogen applications may result in higher fertilizer application costs, this cost may be at least partially offset by reductions in fertilizer application rates. By applying fertilizer closer to the time of maximum crop uptake, less fertilizer may be needed to achieve desired yields. Split applications can also allow for improved estimation of crop needs through the use of tissue tests or nitrate quick tests (a presidedress nitrogen test) during the growing season.

Splitting of nitrogen applications allows for the adjustment of fertilizer application recommendations after planting through the use of test results. Ideally, presidedress nitrogen testing is conducted late enough to minimize the probability of changes in soil N availability before the N is required by the crop, yet early enough to allow additional N to be applied before maximum crop uptake (Beegle, Roth, and Fox). These tests may allow for more accurate nitrogen applications by reducing uncertainty about plant available nitrogen already present in the soil. This reduction of uncertainty can be particularly important when manures or legumes are used to provide nitrogen for crops.

Fox et al. suggest that one of the best uses of a presidedress nitrogen test is in manured fields. Nitrogen testing can help overcome uncertainty concerning nutrient content by providing the farmer with an estimate of nitrogen available to the crop during the growing season. A study by Fuglie and Bosch uses a ‘switching-regression’, simultaneous equations model to assess the impacts of pre-plant soil nitrogen testing on fertilizer use, crop yields, and net returns on corn in Nebraska. The results suggest that when there is uncertainty about the quantity of plant available nitrogen, spring nitrogen testing enables farmers to reduce fertilizer applications without affecting crop yields. However, the use of the preplant nitrogen test had the most significant impact on fertilizer use on fields that were more likely to have a higher level of nitrogen carryover from manure applications and legumes. Nitrogen testing reduced average nitrogen applications by 26 to 31 pounds per acre on farms using manure or legumes in comparison to a reduction of 12 to 19 pounds per acre on farms not using manure or legumes (Fuglie and Bosch).

Shortle et al. found that farmers who used a presidedress nitrogen test in the surveyed area of Pennsylvania reduced nitrogen applications to corn by an average of 42 pounds per acre, approximately a 50 percent reduction. The reductions were greater in dry years when nitrogen losses through leaching and denitrification were below normal. Budget analysis indicated that farm profits increased by an average of $3.82 per acre (Shortle et al). These results suggest that the increased costs associated with the use of nitrogen testing are more than offset by the reductions in fertilizer applications.

A study by Norris and Shabman incorporated a nitrogen mass balance component, through the use of CREAMS, into a multi-year linear programming model to examine farm profit and environmental impacts of four alternative management practices for grain production in eastern Virginia. The alternatives examined include the use of split fertilizer applications, the use of rye and crimson clover cover crops, and the use of poultry litter as an alternative source of nutrients. The results of the study suggest that the use of split applications or use of poultry litter may reduce potential nitrogen losses while increasing net returns implying that significant reductions in nitrogen loss are possible without imposing undue hardship on the producer. In fact, Norris and Shabman found that potential nitrogen losses through runoff, erosion, leaching, and volatilization could be reduced by approximately 35 percent while increasing farm net returns.

In using EPIC to examine nitrate loss to ground and surface water under four alternative fertilization regimes in Richmond County, Virginia, Maiga also found that estimated nitrogen losses were lowest under multiple fertilizer applications. In addition to reducing potential nitrogen losses, mean net returns were higher under the practice of split fertilizer applications (when the application amount was based on the level of soil nitrate) than when only a single set application was used. The results of this study suggest that it may be economically beneficial for farmers to split fertilizer applications and to base applications on soil or tissue tests.

Timing of applications can also be important in the application of animal wastes to cropland. Young and Crowder examine manure storage/management for a representative 45 - cow dairy farm in southeastern Pennsylvania. A linear programming model was used to evaluate the costs and effectiveness of manure storage relative to field losses of nitrogen and phosphorus. Estimates for field losses of nutrients were obtained through the use of CREAMS. When manure is not applied in excess of crop needs, the use of 12-month storage was found to reduce nitrogen losses by 18 percent over systems in which manure was spread daily. The reduction in nitrogen loss resulted because the storage of manure allows for application of manure in spring prior to planting, when nutrients can be most efficiently used by crops. However, when manure was applied in excess of crop needs, the effectiveness of storage in reducing nutrient losses decreased. Net farm returns were fairly constant for the alternative manure management systems. Net returns with twelve-month storage were $400 - $800 less than daily spreading.

Young et al. also used CREAMS in addition to linear programming to evaluate alternative manure handling practices for a dairy farm in Lancaster County, Pennsylvania. While the study found that moderate nutrient loss reductions of up to 10 percent may be achieved with negligible effects on farm profits (1.5 percent reduction), substantial reduction in losses were found to be prohibitively expensive without implementing field-level best management practices (BMPs) such as terraces.

Halstead examined the farm level economic impacts of nutrient management practices for two representative dairy farms in Rockingham County, Virginia using a chance-constrained linear programming model. He examined the impact of nitrogen loss reduction strategies on farm level net returns over variable costs. Results indicated that significant reductions in nitrate loadings were possible with only minor impacts on farmers' net incomes through the use of cost sharing for manure storage and nutrient management planning.

Soil Loss

While the crediting of on-farm sources and better timing of applications can result in significant reductions in nitrogen losses from agricultural sources, nitrogen loss will also be impacted by the amount of soil loss occurring at a site. Since nitrogen is lost through erosion and runoff, any practice that reduces erosion, should reduce the loss of nitrogen attached to soil particles and dissolved in runoff. However, if a practice designed to reduce erosion increases infiltration, it may increase nitrogen loss in percolation or subsurface flows. Erosion is affected by many factors including tillage practices and crop use. The use of winter cover crops can reduce erosion, surface runoff, and leaching into groundwater. In examining the reduction of potential nitrogen losses from livestock farms in Rockingham County, Virginia, Parsons found that the use of a rye cover crop following corn significantly reduced surface and subsurface nitrogen losses, indicating that rye cover reduces nitrogen losses in the fall and winter by absorbing plant available nitrogen (Parsons).

In examining manure storage/management for a representative Pennsylvania dairy farm, Young and Crowder also examine the impact of conservation practices such as conservation tillage, contouring, strip cropping, and residue management on soil and nutrient losses. The use of the conservation practices reduced soil loss from 7.3 tons per acre to 0.6 tons per acre while total nitrogen losses were reduced by up to a third. However, while surface losses of nitrogen were reduced substantially, losses with percolation increased.

Impacts of Farm Characteristics on Nitrogen Loss

The ability to reduce nitrogen losses from a farm and the costs of those reductions will depend at least partially on farm physical and economic characteristics. The impact of farm characteristics on the ability to reduce nutrient losses is illustrated by a study conducted by Bosch and Carpentier for the Lower Susquehanna Watershed in Pennsylvania. In using a microparameter approach to account for differential impacts of a generic performance standard for allowable nitrogen runoff as farm characteristics vary, Bosch and Carpentier's preliminary results imply that the costs of achieving nitrogen reductions vary greatly as farm characteristics change. For example, farms located near to surface water have a lower cost of reducing nitrogen deliveries (Bosch and Carpentier). On these farms, more nitrogen leaving the farm reaches water sources compared to farms further from the water. Also, reducing nitrogen leaching losses is found to be less costly on farms with no existing manure storage facilities. These farms can build storage while farms with storage facilities must turn to more costly options such as reducing livestock numbers.

While the location of the farm in relation to water bodies and presence of animal waste storage facilities may impact the cost of achieving nitrogen loss reductions, soil types and weather patterns will also impact the effectiveness of alternative management practices in achieving nitrogen loss reductions. For example, when water entering the soil system exceeds water outputs, soil with high water-holding capacity can accumulate significant amounts of water before percolation begins. Therefore, these soils are generally less susceptible to leaching losses than soils with low water holding-capacity (Scharf and Alley). Also, weather can affect nitrogen losses. For example, Gustafson found leaching losses to be high in years following a dry year. Apparently, low yield and nitrogen uptake during the dry year left residual nitrogen in the soil which, when followed by normal fertilizer application in the succeeding year, resulted in excess nitrogen and high nitrate concentrations in percolation (Scharf and Alley).

Galeta et al. evaluate crop yields and nitrogen movement to surface and groundwater under nine cropping systems across soils in the High Plains area of Oklahoma using EPIC interfaced with Earthone, a geographic information system (GIS). Four soils were included in the model: Richfield clay loam, Ulysses clay loam, Dalhart loamy fine sand, and Dalhart fine sandy loam. Wide variations are seen in nitrate losses not only for different cropping systems but also across soil type. In general, losses of nitrate in runoff and percolation were higher on the Dalhart soils than on the Richfield and Ulysses clay loams.

Hamlett and Epp conducted a comparative study of seven conservation practices, with and without an improved nutrient management program, on nitrogen and phosphorus losses from representative Pennsylvania farm fields over a 30-year simulation period. The differences in losses resulting from individual practices were examined on three Pennsylvania soils: Wellsboro, Penn, and Edom. These soils were chosen as representative soils for the Upper Susquehanna, Middle Susquehanna, and Lower Susquehanna regions of Pennsylvania, respectively. The conservation practices included no-till, contouring, filter strips, strip cropping, terraces, and sediment and water control basins. Although the adoption of specific practices generally reduced nitrogen and phosphorus losses, the effectiveness of the practices varied widely between soil types and topography. The study by Maiga in Richmond County, Virginia examining four alternative fertilization regimes also finds significant differences in nitrogen losses across soils. Maiga also finds that net returns per acre vary across the soil types examined.

Summary

Due to the belief that farmers' individual goals, such as profit maximization, may not correspond to societal goals, a criticism of voluntary programs is that the necessary reductions in nitrogen loadings from agriculture are unlikely to be met through voluntary programs alone (Abler and Shortle). However, some studies conducted recently in the Chesapeake Bay Area of Virginia have reached the conclusion that it may be possible to achieve significant reductions of nitrogen losses through the adoption of alternative fertilizer management practices while maintaining farm profit goals (Norris and Shabman; Parsons).

While it may be possible to achieve the desired reductions in nitrogen loss through the use of alternative management practices, the studies reviewed suggest that the magnitude of the reductions achieved by nutrient management are affected by not only specific management practices but also by the physical characteristics of the farm. However, while farm-level studies provide information about the costs of achieving reductions in nitrogen loss under a specific set of conditions, the results are contingent on the specific characteristics contained in the model (Opaluch and Segerson). In the long term, it is unclear whether improvements in nitrogen management alone will result in sufficient reduction in nitrogen loadings (National Research Council).

Estimating the effectiveness of nitrogen management programs will require detailed research to determine if programs have actually altered farmer behavior. In Virginia, 1,000 nutrient management plans have already been developed for 240,000 acres of cropland (Perkinson). It is a general assumption behind the development of these plans that reducing nutrient application rates or altering application and storage practices will lead to reduced nutrient losses while increasing profitability. However, it is unknown what level of reduction in potential nutrient losses to surface and groundwater results from compliance with the plans. Current understanding of the effect of farming systems on soil and water quality is not sufficient for making quantitative estimates of how much soil and water quality will improve as a result of the use of alternative practices or management methods (National Research Council). As a result, the environmental and economic tradeoffs implied by voluntary nutrient management plans are uncertain. A number of factors, including impact on yields and policy type, affect the loss of profits farmers will experience from practices to reduce water quality damage (Bosch and Wolfe). Determining the impacts of nutrient management plans on nutrient loss and farm income requires identifying those participating in the program, estimating before and after nutrient management practices and the resulting changes in nutrient losses. Also, without knowing the degree of the impact nutrient management plans have had on nitrogen losses, it is also impossible to determine if losses could be reduced even further.

Implications for Empirical Model

While it is difficult to determine what impact alternative management practices utilized through the development of nutrient management plans have had on nitrogen losses, previous studies do allow for the identification of practices that are likely to have been the most successful in achieving nitrogen loss reductions (Crowder and Young; Crowder et al.; Diebel; Hall and Risser; Maiga; Norris and Shabman; Parsons). Clearly, the most important step in achieving a reduction in potential nitrogen losses is to reduce the amount of excess nitrogen present in the soil system. Although the timing and method of application clearly have an impact on potential losses, the amount of the application seems to be more significant. Once the application rate is more in harmony with plant needs, other management practices become important in achieving further reductions. The use of cover crops appears to be successful in helping to stabilize nitrogen already present in the soil system. Also, the use of split fertilizer applications can allow for application of fertilizers closer to the time of plant need and also for the use of soil and tissue tests after the plant has begun to grow. The use of these tests during the growing season can allow for a more accurate estimation of nutrient availability and therefore refinement of fertilizer application rates. The combination of changes in timing of applications and possible reductions in application rates may greatly reduce the potential for nitrogen losses from the soil system. Although it is clear that the incorporation of fertilizers, particularly manures, can result in reductions of volatilization losses, it is not clear that this will result in an overall reduction in nitrogen losses from the soil system. Incorporation may increase erosion, as well as surface and subsurface losses of nitrogen.

While several studies have examined the varying impacts of nutrient management practices across soils, the studies discussed above examine nitrogen loss reductions when alternative management practices are applied to the farm as a whole. One area that has not been investigated is the possibility of reducing farm level nutrient losses by targeting alternative management practices within individual farms to specific fields or soils. While crop management practices may have significant impacts on nutrient losses, the variations in losses across soil types may become more important when engaging in nutrient management planning at the farm (rather than field) level. For example, it may be possible to reduce farm level nitrogen losses significantly through alternative routing of manure and commercial fertilizer applications within a farm based on information about soils and slopes. For example, significant reductions in total nitrogen losses may be achieved through the higher application of nutrients (particularly from manure) on those soils and slopes less susceptible to nutrient losses. Increased nutrient losses on such fields may be more than offset by reductions on soils more susceptible to nutrient losses and therefore result in the same level of reductions at a lower cost or greater reductions at the same cost.

Chapter 3: Nutrient Management Planning on Four Virginia Livestock Farms

Introduction

The effects of nutrient management practices on farm profit and farm-level nitrogen loss across sample livestock farms in Virginia are analyzed for four case farms: 1) Southwestern Virginia Dairy, 2) Shenandoah Valley Dairy, 3) Southeastern Virginia Crop and Swine, and 4) Piedmont Poultry. These farms were chosen through consultation with nutrient management specialists and project managers of the Division of Soil and Water Conservation to represent a cross section of Virginia livestock producers. The selected farms have nutrient management plans with sufficient information to analyze nutrient losses and economic performance before and after the implementation of the plan. The purpose of the analysis is to estimate field-level reductions in nitrogen losses and the costs incurred by the producer resulting from implementation of nutrient management planning. This analysis includes examination of the effect of identified livestock farm physical characteristics on the results of nutrient management practices, specifically the impact of soil type and slope on the cost-effectiveness of nutrient management practices. Results of the case farm analyses are used in determining the range of alternatives included in the linear programming model presented in Chapter 4.

Procedures

Estimating Changes in Crop Yields and Nutrient Losses

The Erosion Productivity Impact Calculator (EPIC), is used to estimate the changes in crop yields and nitrogen losses before and after the implementation of the plan. EPIC is a USDA-developed model capable of simulating multi-year interactions of weather, hydrology, erosion, mineral nutrients, plant growth, pesticides, soil tillage, and crop management practices (Williams and Renard, Sharpley and Williams). While EPIC was initially developed to assess the effect of soil erosion on soil productivity, most recent development has focused on problems involving water quality (Williams). EPIC has been utilized and validated in over 200 applications with widely varying crop and soil conditions in many sections of the United States, Europe, and Australia.

EPIC's nutrient cycling estimates have been found to be consistent with field measurements (Jones et al. 1984, Jones et al. 1985, Smith et al.). EPIC estimates of water percolation and nitrogen leaching have been found to agree with soil leaching indexes based on soil characteristics and seasonal precipitation (Williams and Kissell).

A recent study conducted by Parsons, Pease and Martens examining the ability of EPIC to reliably simulate corn yields on three Virginia soils found that EPIC simulations did provide reasonable estimates of observed yields on Virginia soils with either manure or inorganic fertilizer treatments. "EPIC simulated yields means were not different from measured yield means for all treatments ($p \leq 0.05$) and generally had smaller standard deviations" (Parson, p. 57). However, results of the study also underscored the importance of site specific soil and other model parameter specification (Parsons, Pease, and Martens).

Necessary data for EPIC simulations of each case farm were obtained through evaluation of nutrient management plans, examination of soil surveys, and interviews with producers and nutrient management specialists. The model is calibrated by comparing EPIC estimated yields under current and previous management practices to those obtained by the farmer. Also, all results were examined by a soil scientist, Dr. James C. Baker, at Virginia Tech to determine if estimates provided by EPIC for yields and nutrient losses were realistic.

A set of one-hundred simulations is run for each combination of crop rotation, soil, slope, and fertilizer management practices. Reported results are annual averages for the one-hundred simulations[4]. Weather for the simulations is generated internally by EPIC based on weather parameters established for the area.[5] Weather parameters have been established for each of the case farms using historical weather data. Although the weather created for each year of the one-hundred EPIC simulations is different, the long term statistical properties of the weather parameters are maintained. While each of the hundred years of weather is different (on a particular farm), the sequence of weather used for each alternative on a farm is identical.[6] This allows for comparison of results across alternatives examined without the need to consider changes in yields or nutrient loss due to variation in weather patterns.

The first year in each of the one hundred simulations is not considered in the results in order to allow for start-up time of the model. Alternative management practices are simulated for crop rotations rather than individual crops. Therefore, if EPIC is run for the full year during the first year of the simulation, the existence of a crop already present at (planted prior to) the beginning of the year is not recognized. Therefore, erosion and nutrient losses may be extremely high. If the simulation is started in the middle of the year when the first crop is planted, erosion and nutrient loss values estimated by EPIC will not reflect a full year.

Total nitrogen losses are estimated by nitrate loss with runoff, organic nitrogen loss with sediment, and mineral nitrogen loss in subsurface flow and percolation. Volatilization losses of nitrogen are not included in total nitrogen loss. Estimated nutrient losses in EPIC are losses at the edge of the field and the edge of the root zone. Therefore, nitrogen losses at the field level only represent *potential* , not actual, loadings to water sources. Whether losses at the field level contribute to contamination of nearby water bodies will depend on numerous environmental characteristics of the area. For instance, distance to water sources will impact whether field level losses contribute to pollution problems as these losses can be absorbed by adjoining land areas or lost to the atmosphere. Also, some soils may provide enormous ‘sinks’ which absorb nutrients lost through percolation.

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[4] Other descriptive statistics for EPIC simulation results are included in Appendixes A through D.

[5] More detailed explanation concerning weather parameters for each case farm is included in Appendixes A through D.

[6] As long as the seed values for weather generation in EPIC are the same, the sequence of weather generated for any set of simulations at a specific site will be identical.

Partial Budget Analysis

The impacts of the nutrient management plans on farm net income are examined through the development of partial budgets. The budgets include information concerning only the changes resulting from the implementation of the nutrient management plan. Information necessary for the development of the budgets was obtained primarily through farmer interviews. However, some supplementary information was used. The use of any cost estimate not obtained specifically from the producer is detailed in the Appendix for each farm.

Farm 1: Southwestern Virginia Dairy

Farm Characteristics

Farm 1 is a dairy operation located in Pulaski County, Virginia. The farm consists of 660 acres: approximately 90 acres of woodland, 195 acres of pasture, and 375 acres of cropland. Each year, approximately 150 acres are planted with corn, 50 acres are wheat, 50 acres are barley, 40 acres are rye for seed, and 85 acres are alfalfa. The farm has 110 dairy cows. The primary crop rotation is a two year rotation of rye cover and corn, followed by a small grain. Fields are not generally switched between corn and alfalfa. All crop residue is left on the field. No-till management practices were already utilized before the implementation of the plan. The predominant soils on the farm are Frederick and Groseclose. These are deep loam soils that do not have a seasonal high water table within six feet of the surface. The Groseclose soil has more silt and less clay in the lower part of the profile than the Frederick soil. Both soils are well suited for cultivated crops (United States Department of Agriculture, 1985). The soil slopes range from B (2-7 percent) to D (15-25 percent). Fields containing D slopes are generally kept in permanent grass.

Changes in Management Practices due to Nutrient Management Planning[7]

The major impact of the plan on the farm was education concerning the management of nutrients, particularly the importance of crediting manure for nutrient content.[8] Before the implementation of the plan, manure was not credited for nitrogen and phosphorus content. Commercial fertilizer was applied in a single application prior to planting without considering nutrients already present in the soil. Although the application rate of manure has not changed, manure tests are now performed in order to credit manure for nutrient content when deciding amounts of commercial fertilizer to be applied and presidedress soil tests (nitrate quick tests) are performed. Commercial fertilizer is applied in split applications. Changes in fertilizer application rates are shown in Table 3.1.

[7] The set up of EPIC simulations for Farm 1 are explained in more detail in Appendix A.
[8] Manure nutrient values for Farm 1 are contained in Appendix A.

Table 3.1: Plant Available Nitrogen Applications, Farm 1

Management Practice / Crop Rotation	Acres	Commercial N (lb./ac)	Manure App. (gallons/ac)	Plant Available Manure N[a] (lb./ac)	Annual Average N Application for Rotation (lb./ac)
Before Plan: Corn	250	140	3000	29	
Wheat		100	3000	29	163.5
Rye Cover			3000	29	
After Plan: Corn	250	110	3000	29	
Wheat		65	3000	29	131
Rye Cover			3000	29	

[a] Plant available manure nitrogen is calculated following procedures outlined in the Nutrient Management Handbook (Virginia Department of Conservation and Recreation, 1993).

Impact of Plan on Nitrogen Losses

With the implementation of the current management practices, nutrient losses are consistently reduced on all soil types and slopes. The amount of the reduction achieved varies with both slope and soil type. As the degree of the slope increases, the actual amount of reduction in nitrogen loss (in pounds per acre) increases. However, the percentage reduction is larger on the flatter slopes. On the Frederick soil with a 4.5 percent slope, a 36 percent reduction in nitrogen loss is achieved while a 27 percent reduction in nitrogen loss is achieved on the 10.5 percent slope. This trend is also observed on the Groseclose soil where a 38 percent reduction is seen on the 4.5 percent slope while a 26 percent reduction is seen on the 10.5 percent slope and a 19 percent reduction is seen on the 16.5 percent slope. After the implementation of the plan, the amount of nitrogen loss remains highest on the steepest slopes. Overall, the Groseclose soil has a lower nitrogen loss and a smaller reduction in nitrogen losses than the Frederick soil. Average nitrogen loss for Farm 1 is reduced by 27 percent with the adoption of the nutrient management plan. Detailed information concerning crop yields and nitrogen losses through individual nitrogen loss pathways is included in Appendix A.

Table 3.2: Effect of Nutrient Management Plan on Annual Nitrogen Loss, Farm 1

Soil Type and Slope	Before Plan (lb./ac)	After Plan (lb./ac)	Reduction (lb./ac)	Reduction (%)
Frederick, 4.5 %	24.8	15.8	9.0	36
Frederick, 10.5 %	40.7	29.7	11.0	27
Frederick, 16.5 %	62.7	49.4	13.3	21
Groseclose, 4.5 %	22.6	13.6	9.0	40
Groseclose, 10.5 %	38.5	28.5	10.0	26
Groseclose, 16.5 %	61.8	49.8	12.0	19
Newark, 1 %	35.4	23.9	11.5	32
Average for All Soils [a]	**47.3**	**34.5**	**12.8**	**27**

[a] Weighted average based on amount of each soil present on farm as determined through examination of soil survey for farm.

Impact of Plan on Farm Income

First, the additional cost of new practices resulting from the implementation of the nutrient management plan is calculated. These practices include the use of the nitrate quick test and split fertilizer applications. Although the timing of the nitrate quick test varies with the crop, it has been assumed that the test is performed once per year on each field prior to the sidedress fertilizer application resulting in an additional cost of $1,250. In addition to the use of the nitrate quick test, manure was not consistently applied to all cropland before the implementation of the plan due to the distance of some fields and failure (by prior management) to fully realize the value of manure nutrients. Although this practice is not modeled due to difficulty in determining which land did or did not receive manure applications prior to the plan, an estimate of the increase in cost is included in the budget.[9] Currently, manure is uniformly applied to all cropland resulting in an increased cost of approximately $940.

Although additional costs are incurred, commercial fertilizer use was reduced as a result of crediting manure for nutrient content. This reduction in commercial fertilizer use results in a savings of $2,665. As no change has occurred in yield, gross income has not changed. The net change in income is + $395 indicating that the nutrient management plan increased net income.

Table 3.3: Economic Impact of Nutrient Management Plan, Farm 1 [a]

Additional Costs	Reduced Income	Additional Income	Reduced Costs	Net Income Change
$2270	$0	$0	$2665	$395

[a] Details of the budget are shown in Table A.4.

Farm 2: Shenandoah Valley Dairy

Farm Characteristics

Farm 2 is a dairy farm located in Augusta county. The entire farm consists of approximately 1,025 acres and approximately 160 dairy cows. However, the area evaluated includes only the portion of the farm surrounding the dairy, a total of 314 acres: approximately 50 acres of pasture and 264 acres of cropland. Each year, approximately 102 acres are planted to corn, 69 acres are barley double-cropped to soybeans, 23 acres are wheat followed by clover cover, and 70 acres are alfalfa. The 70 acres in alfalfa are not modeled for the case study analysis as no changes have occurred in management practices associated with alfalfa. Also, the 10 acres coming out of alfalfa into corn are not modeled. Currently, two rotations (excluding alfalfa) are followed on the farm: 1) corn, barley, soybean and 2) corn, wheat, clover cover. However, prior to the adoption of the plan, three alternative rotations were used: 1) corn, barley, sudex, 2) corn, rye cover, corn, barley, and 3) corn, rye cover. The predominant soils on the farm are well drained Frederick and Christian loams. However, Nixa, Timberville, and Fluvaquents are also present. The Nixa soil is a very cherty, poor quality soil while the Timberville soil is a well drained bottom soil (United States

[9] For further explanation of reason for not modeling the change in manure application to some cropland, see Appendix A.

Department of Agriculture, 1979). Soils present on the farm have slopes ranging from B (2-7 percent) to E (25-45 percent). The D (15-25 percent) and E (25-45 percent) slopes are generally present only in pasture.

Changes in Management Practices due to Nutrient Management Planning[10]

The major impact of the plan has been modification of the application of both commercial and manure fertilizers. Prior to the adoption of the plan, manure application was concentrated on the pasture and 38 acres of cropland closest to the barnyard. In addition, manure was not credited for nutrient content in determining application rates of commercial nitrogen to crops.[11] On this farm, there was a two-stage phased-in adoption of the current nutrient management plan.[12] Adoption of the initial nutrient management plan coincides with the installation of the manure pit which allowed for manure to be applied to all cropland. With the implementation of nutrient management planning, manure applied to cropland is credited for nutrient content and commercial fertilizer usage is reduced by 60-100 pounds per acre (by the time the second plan is introduced) depending on crop and rotation (see Tables 3.4 and 3.5). Average annual per acre application was reduced by 74 pounds, a 41 percent reduction.

Table 3.4: Plant Available Nitrogen Applications Before Plan, Farm 2

Management Practice / Crop Rotation	Acres	Commercial N (lb./ac)	Semi-Solid Manure App. (tons/ac)	Plant Available Manure N[a] (lb./ac)	Annual Average N Application for Rotation (lb./ac)
Corn	38	160			236
Barley		110	15.8	79	
Sudex		80	15.8	43	
Corn	94	150			225
Barley		110			
Corn		150			
Rye		40			
Corn	52	150			190
Rye		40			
Pasture	50		28.2	141	141
Total Acres / Average Annual N Application[b]	**234**	**161**		**40**	**201**

[a] Plant available manure nitrogen is calculated following procedures outlined in the Nutrient Management Handbook (Virginia Department of Conservation and Recreation, 1993).
[b] Weighted average based on amount of each rotation present on farm.

[10] An explanation of EPIC simulations for Farm 2 is included in Appendix B.
[11] Manure nutrient content values for Farm 2 are included in Appendix B.
[12] The two stages of nutrient management planning for this farm are detailed in Appendix B.

Table 3.5: Plant Available Nitrogen Applications After Plan, Farm 2

Management Practice / Crop Rotation	Acres	Commercial N (lb./ac)	Liquid Manure Application (gallons/ac)	Plant Available Manure N[a] (lb./ac)	Annual Average N Application for Rotation (lb./ac)
Corn	132	60	6000	70	120
Barley		50	6000	60	
Soybean					
Corn	52	40	6000	70	110
Wheat		50	6000	60	
Clover					
Pasture	50	40	5 tons semi-solid	25	65
Total Acres / Average Annual Application[b]	**234**	**50**		**55**	**106**

[a] Plant available manure nitrogen is calculated following procedures outlined in the Nutrient Management Handbook (Virginia Department of Conservation and Recreation, 1993).
[b] Weighted average based on amount of each rotation present on farm.

Impact of Plan on Nitrogen Losses

With the implementation of the current management practices, nutrient losses are consistently reduced on all soil types and slopes (see Table 3.6). These reductions are achieved through the reduction in total plant available nitrogen applications to all crops and pasture. The amount of nitrogen loss reduction achieved on the farm varies with soil type, slope, and crop rotation. Regardless of rotation or management practice, nitrogen losses are consistently higher on the Nixa soil. The higher losses are expected since the Nixa soil is a poor quality, extremely gravelly soil which results in high percolation losses.

The most significant decreases in nitrogen losses are achieved on the steeper pasture and the Nixa soil (regardless of rotation). The reduction in fertilizer application to Nixa soil with the adoption of the plan results in significant reductions in percolation losses. The reduction in losses from pasture are primarily the result of reduced organic losses associated with the reduction in manure application (see Tables B.5 and B.8). The high application of manure to pasture before the adoption of the nutrient management plan resulted in high organic nitrogen losses with sediment, particularly on the steeper slopes.

In cropland, the smallest reductions in nitrogen losses are seen on the Frederick soil. This soil has smaller initial losses than the Nixa and Timberville soils with similar slopes in each rotation. Average nitrogen loss for Farm 2 is reduced by 33 percent with the adoption of the nutrient management plan. Detailed information concerning crop yields and nitrogen losses through individual loss pathways is included in Appendix B.

Table 3.6: Effect of Nutrient Management Plan on Annual Nitrogen Loss, Farm 2

Crop Rotation	Soil Type and Slope	Before Plan (lb./ac)	After Plan (lb./ac)	Reduction (lb./ac)	Reduction (%)
Corn, Barley, Sudex (before plan) to Corn, Barley, Soybean (after plan)	Frederick, 4.5 %	28.4	21.7	6.7	23.6
	Frederick, 10.5 %	49.4	45.4	4.0	8.1
	Timberville, 2 %	33.1	21.5	11.6	35.0
Corn, Rye, Corn, Barley (before plan) to Corn, Barley, Soybeans (after plan)	Frederick, 4.5 %	25.6	21.7	3.9	15.2
	Frederick, 10.5 %	47.7	45.4	2.3	4.8
	Timberville, 2 %	28.9	21.5	7.4	25.6
	Nixa, 4.5 %	120.5	71.2	49.3	40.9
	Nixa, 10.5 %	126.0	79.4	46.6	37.0
Corn, Rye (before plan) to Corn, Wheat, Clover (after plan)	Frederick, 10.5 %	45.3	35.7	9.6	21.2
	Frederick, 16.5 %	72.7	63.4	9.3	12.8
	Nixa 10.5 %	126.8	66.5	60.3	47.6
Pasture	Frederick, 4.5 %	29.1	22.1	7.0	24.1
	Frederick, 10.5 %	57.1	33.8	23.3	40.8
	Frederick, 16.5 %	97.9	50.3	47.6	48.6
	Frederick, 26.5 %	188.5	94.4	94.1	49.9
Average Loss		61.2	40.8	20.4	33.3

[a] Weighted average based on amount of each rotation and soil present on farm. Amount of each soil is determined through examination of soil survey for farm.

Impact of Plan on Farm Income[13]

The additional costs resulting from the adoption of new management practices outlined in the nutrient management plan are calculated first. These costs include the installation of the manure pit, purchase of the pump, purchase of the spreader, the additional costs associated with spreading manure to cropland, and the increase in commercial fertilizer application to home pasture. The adoption of the nutrient management plan increases costs by $7,643.

While the nutrient management plan does increase some costs, other costs are reduced. The reductions in costs are associated with the decrease in commercial fertilizer application to cropland

[13] Further explanation of partial budget development is included in Appendix B.

and decrease in the costs associated with the daily scrape and haul of semi-solid manure. These changes in management practices result in a cost reduction of $11,206.

Since the changes in crop rotation are not considered and crop yields did not change, income does not change. The net change in income with the implementation of the plan is + $3,563 indicating that nutrient management has increased net income.

Table 3.7: Economic Impact of Nutrient Management Plan, Farm 2 [a]

Additional Costs	Reduced Income	Additional Income	Reduced Costs	Net Income Change
$7643	$0	$0	$11206	$3563

[a] Details of the budget are shown in Table B.9.

Farm 3: Southeastern Virginia Crop and Swine

Farm Characteristics

Farm 3 is a crop and swine farm located in Isle of Wight county near Smithfield. The entire farm consists of approximately 1,100 acres. However, the nutrient management plan for the farm applies to only 670 acres: approximately 605 acres of cropland and 65 acres of pasture. Two three-year crop rotations are followed on the farm: 1) peanuts, wheat double-cropped to soybeans, rye cover, corn, rye cover and 2) peanuts, wheat double-cropped to soybeans, rye cover, cotton, rye cover. Approximately two thirds of cropland is in the second rotation. Pasture is clover-fescue. Annual hog production is approximately 4,928 hogs.

The predominant soils on the farm are Rumford and Uchee which are nearly level. Rumford is a very deep, somewhat excessively drained loamy sand well suited to cultivated crops. Uchee is also a very deep, well drained loamy sand (United States Department of Agriculture, 1986). Small percentages of Emporia, Peawick, Slagle, Chickahominy, and Kinston are also present. Emporia is a very deep, well drained, fine sandy loam while Peawick is a very deep, moderately well drained, silt loam. Slagle sandy loam is also very deep and moderately well drained. All of these soils are well suited to cultivated crops (United States Department of Agriculture, 1986). Chickahominy silt loam and Kinston loam are very deep, poorly drained soils not well suited to cultivated crops. However while the Kinston soil is also poorly suited to pasture grasses and legumes, Chickahominy is moderately well suited to these crops (United States Department of Agriculture, 1986). All of the soils on the farms have slopes ranging from 0 to 6 percent. Chickahominy is present only in pasture.

Changes in Management Practices due to Nutrient Management Planning[14]

The major change in management practices resulting from the adoption of the plan has been the utilization of nutrients available in manure. With the construction of two hog houses and slurry

[14] An explanation of EPIC simulations for Farm 3 is included in Appendix C.

storage, the farmer has been able to more effectively use manure. The slurry storage has sufficient capacity to hold 354 days of manure production (approximately 726,629 gallons capacity) which allows the farmer to store manure until its use will be most beneficial. Before the slurry storage was installed, manure was drained into a lagoon. All of the manure was applied to approximately 50 acres of corn in late April or early May. However, the manure was not credited with nutrient content due to uncertainty about nutrient content.

Currently manure is applied to all wheat and corn while cotton receives none. Some rye also receives manure. Any remaining manure is applied to pasture. Fertilizer application rates are shown in Tables 3.8 and 3.9.

Table 3.8: Plant Available Nitrogen Applications Before Plan, Farm 3

Management Practice / Crop Rotation	Acres	Commercial N (lb./ac)	Manure App. (acre inch [c])	Plant Available Manure N[a] (lb./ac)	Annual Average N Application for Rotation (lb./ac)
peanuts	51.7				97
wheat		125			
soybeans					
rye cover					
corn (without manure)		165			
rye cover					
peanuts	150				193
wheat		125			
soybeans					
rye cover					
corn (with manure)		165	2	290	
rye cover					
peanuts	403.3				63
wheat		125			
soybeans					
rye cover					
cotton		65			
rye cover					
Pasture	65	60			65
Total Acres / Average Annual Application [b]	**670**	**73**		**22**	**95**

[a] Plant available manure nitrogen is calculated following procedures outlined in the Nutrient Management Handbook (Virginia Department of Conservation and Recreation, 1993).
[b] Weighted average based on amount of each rotation present on farm.
[c] One acre inch is 27,154 gallons.

Average annual plant available nitrogen application is reduced by 39 pounds per acre, a 41 percent reduction. This reduction occurs as a result of the application of manure to all cropland so as not to exceed crop requirements. With the crediting of manure nutrients, commercial nitrogen applications are also reduced on all cropland. Plant available manure nitrogen increases after the implementation of the nutrient management plan due to changes in the application method of manure. Prior to the plan, manure was broadcast at high application rates resulting in high nutrient losses. After the plan, manure is incorporated or injected.

Table 3.9: Plant Available Nitrogen Applications After Plan, Farm 3

Management Practice / Crop Rotation	Acres	Commercial N (lb./ac)	Manure App. (gallons/ac)	Plant Available Manure N[a] (lb./ac)	Annual Average N Application for Rotation (lb./ac)
peanuts	201.7				72
wheat		15	2000	55	
soybeans					
rye cover					
corn		15	3000	98	
rye cover			1000	33	
peanuts	403.3				45
wheat		15	2000	55	
soybeans					
rye cover					
cotton		65			
rye cover					
Pasture	65	60	1000	15	75
Total Acres / Average Annual Application[b]	**670**	**25**		**31**	**56**

[a] Plant available manure nitrogen is calculated following procedures outlined in the Nutrient Management Handbook (Virginia Department of Conservation and Recreation, 1993).
[b] Weighted average based on amount of each rotation present on farm.

Impact of Plan on Nitrogen Losses

With the implementation of the nutrient management plan, nitrogen losses are consistently reduced on all soils and slopes in both the corn and cotton rotations. Nitrogen loss reductions range from -6 to 77 percent (see Table 3.10). The highest reductions are seen on soils in corn rotation that received manure from the lagoon previous to the adoption of the nutrient management plan. This is due to the high volume of manure previously applied to only a few acres which resulted in extremely high nitrogen applications and high nitrogen losses.[15]

Generally, as soil slope increases from 1 percent to 4.5 percent, the percentage of nitrogen loss reduction decreases while the absolute reduction increases. The only exception to this trend is the Emporia soil in the corn rotation receiving no manure before the plan. The reduction in nitrogen loss on all soils is due to the decreased total nitrogen application resulting from the implementation of the plan (see Tables 3.7 and 3.8). On most soils and slopes, the percentage of reduction in nitrogen loss is smaller in the cotton rotation than the corn rotation. Also, absolute nitrogen loss remains higher from soils in the cotton rotation . The lower percentage reduction in nitrogen loss from soils in the cotton rotation is likely due to the fact that management of cotton was not changed with the implementation of the plan. For more detailed information about crop yields and nitrogen losses see Appendix C.

Impact of Plan on Farm Income[16]

The additional costs resulting from the implementation of new management practices associated with the nutrient management plan are calculated first. The cost of spreading manure to cropland includes the annualized costs of construction of the manure storage, purchase of the pump, purchase of the honey wagon, and the cost of time and fuel associated with the spreading of manure. The adoption of the nutrient management plan increases costs $15,041 annually.

In addition, the reduction in total plant available fertilizer applications results in a reduction of crop yields (as estimated by EPIC). Therefore the reduction in income must be calculated. The total reduction in income resulting from the change in crop yields is $2,195 annually.

With the construction of the manure slurry, the application of commercial fertilizers is reduced. Commercial nitrogen application to corn was reduced by 150 pounds per acre while the application to wheat was reduced by 110 pounds per acre. Phosphorus applications are eliminated. These reductions in commercial fertilizer use result in a savings of $12,419 annually.

With the purchase of equipment to spread manure, it was no longer necessary to custom hire to pump the lagoon. This results in an estimated savings of $5,291. The net change in income is + $473 indicating that the nutrient management plan increased net income.

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[15] Further explanation concerning the modeling of manure applications prior to the adoption of the plan see Appendix C.

[16] A more detailed explanation of the partial budget analysis is contained in Appendix C.

Table 3.10: Effect of Nutrient Management Plan on Annual Nitrogen Loss,Farm 3

Crop Rotation	Soil Type and Slope	Before Plan (lb./ac)	After Plan (lb./ac)	Reduction (lb./ac)	Reduction (%)
peanuts, wheat, soybeans, rye cover, corn (without manure), rye cover	Emporia, 1 %	22.6	15.8	6.8	30.0
	Emporia, 4.5 %	31.0	20.7	10.3	33.1
	Kinston, 2 %	32.7	23.1	9.7	29.5
	Peawick, 1 %	25.1	12.6	12.4	49.5
	Peawick, 4.5%	31.5	19.4	12.1	38.3
	Rumford, 2 %	32.2	17.8	14.4	44.8
	Slagle, 4.5 %	28.2	18.8	9.5	33.5
	Uchee, 1 %	22.0	11.6	10.5	47.5
	Uchee, 4.5 %	35.1	22.1	13.0	37.0
peanuts, wheat, soybeans, rye cover, corn (with manure), rye cover	Emporia, 1 %	50.9	15.8	35.1	69.0
	Emporia, 4.5 %	60.7	20.7	40.0	65.9
	Kinston, 2 %	60.1	23.1	37.0	61.6
	Peawick, 1 %	55.8	12.6	43.1	77.3
	Peawick, 4.5%	64.9	19.4	45.5	70.1
	Rumford, 2 %	69.9	17.8	52.2	74.5
	Slagle, 4.5 %	58.6	18.8	38.8	67.4
	Uchee, 1 %	48.4	11.6	36.8	76.1
	Uchee, 4.5 %	61.9	22.1	39.8	64.3
peanuts, wheat, soybeans, rye cover, cotton, rye cover	Emporia, 1 %	26.5	15.3	11.2	42.2
	Emporia, 4.5 %	34.7	23.4	11.3	32.6
	Kinston, 2 %	34.0	24.8	9.2	26.9
	Peawick, 1 %	27.0	15.5	11.5	42.6
	Peawick, 4.5%	33.3	22.3	11.1	33.2
	Rumford, 2 %	37.5	22.4	15.1	40.2
	Slagle, 4.5 %	31.4	21.2	10.2	32.5
	Uchee, 1 %	25.3	14.1	11.3	44.4
	Uchee, 4.5 %	39.7	26.0	13.6	34.4
Pasture	Chickahominy, 1 %	33.8	34.7	-1.3	-3.9
	Kinston, 2 %	48.9	50.5	-1.6	-3.2
	Peawick, 1 %	49.1	51.8	-2.7	-5.5
	Slagle, 4.5 %	41.1	42.2	-1.2	-2.8
Average Loss[a]		41.3	22.8	18.5	44.9

[a] Weighted average based on amount of each rotation and soil present on farm. Amount of each soil is determined through examination of soil survey for farm.

Table 3.11: Economic Impact of Nutrient Management Plan, Farm 3 [a]

Additional Costs	Reduced Income	Additional Income	Reduced Costs	Net Income Change
$15041	$2195	$0	$17710	$473

[a] Details of the budget are shown in Table C.9.

Farm 4: Piedmont Poultry

Farm Characteristics

Farm 4 is a poultry and beef operation located in Amelia county. The farm consists of approximately 112 acres of pasture: 80.6 acres are clover-fescue while the remaining 31.2 acres are orchard grass-clover. However, all pasture is modeled as clover-fescue.[17] The farm has 5 broiler houses which produce approximately 680,000 broilers and 750 tons of poultry litter annually. Two soils are present on the farm: Cecil and Appling. The Cecil soil is present in B (2-7%) and C (8-15%) slopes while the Appling is present in only B slope. Theses soils are acid, low base status soils with only moderate plant available soil water storage capacity. These two soils are the top two soils in acreage in Virginia.

Changes in Management Practices due to Nutrient Management Planning[18]

The major change in management practices resulting from the plan has been the better use of poultry litter. With the construction of two storage sheds and a composter, the farmer has been able to more effectively use the available litter. The storage sheds allow the farmer to store excess litter which is then sold to other producers in the area. Previous to the plan, pasture received litter at a rate of 4 tons per acre while no commercial fertilizer was used. With the implementation of the nutrient management plan, litter application was reduced to 3 tons per acre. Pasture does not receive commercial fertilizer. Although the amount of manure applied to pasture has changed, the timing of applications has not changed as a result of the plan. As a result of the nutrient management plan, plant available nitrogen applications are reduced by 51 pounds per acre, a 29 percent reduction (see Table 3.12).

In addition to changes in fertilizer application rates, the method of poultry carcass disposal has been altered. Prior to the plan, dead birds were incinerated. Now, through composting, those nutrients are recovered.

Table 3.12: Plant Available Nitrogen Applications to All Pasture, Farm 4[a]

Management Practice	Acres	Commercial N (lb./ac)	Manure Application (tons/ac)	Plant Available Manure N[a] (lb./ac)	Annual Average N Application for Rotation (lb./ac)
Before Plan	111.8	0	4	175	175
After Plan	111.8	0	3	124	124

[a] Plant available manure nitrogen is calculated following procedures outlined in the Nutrient Management Handbook (Virginia Department of Conservation and Recreation, 1993).

[17] See Appendix D for further explanation.
[18] The set up of EPIC simulations for Farm 4 is explained in more detail in Appendix D.

Impact of Plan on Nitrogen Losses

With the adoption of the nutrient management plan, nitrogen and phosphorus losses are reduced below those estimated for management practices used before the first nutrient management plan. Nitrogen losses are 12 to 29 percent lower while phosphorus losses are 27 to 43 percent lower than those occurring before the adoption of the nutrient management plan (see Table 3.13). The highest reduction in nitrogen and phosphorus losses occurs in fields used for grazing. While lower reductions in nutrient losses are seen on pasture used for hay only, these fields have lower losses regardless of poultry litter application rate. For all pasture uses, the percentage reduction generally decreases as slope increases while the absolute reduction increases with slope. Overall, total nitrogen loss is reduced by an average of 22.5 percent below that which occurred before the adoption of a nutrient management plan.

Table 3.13: Effect of Nutrient Management Plan on Annual Nitrogen Loss,Farm 4

Crop Rotation	Soil Type and Slope	Before Plan (lb./ac)	After Plan (lb./ac)	Reduction (lb./ac)	Reduction (%)
grazing and hay	Cecil Soil, 4.5 %	18.0	13.1	4.9	27.2
	Cecil Soil, 10.5 %	50.5	39.8	10.7	21.2
	Appling Soil, 4.5 %	14.1	10.4	3.7	26.2
stockpiled in fall	Cecil Soil, 4.5 %	19.6	14.2	5.4	27.6
	Cecil Soil, 10.5 %	46.2	37.1	9.1	19.8
	Appling Soil, 4.5 %	18.9	13.4	5.5	29.1
hay only	Cecil Soil, 4.5 %	7.4	6.5	0.9	12.2
	Cecil Soil, 10.5 %	29.1	25.2	3.9	13.4
Average Loss		21.8	16.9	4.9	22.5

[a] Weighted average based on amount of each rotation and soil present on farm. Amount of each soil is determined through examination of soil survey for farm.

Impact of Plan on Farm Income[19]

The additional costs resulting from the adoption of new management practices outlined in the nutrient management plan are calculated first. These costs include the annualized costs of construction of two storage sheds and one composter, the purchase of a spreader, the additional time required to clean out the poultry houses, the time required for composting, and the cost of delivering litter to other producers in the area. The adoption of the nutrient management plan increases costs by $3,308.

[19] A more detailed explanation of the partial budget analysis is included in Appendix D.

With the reduction in poultry litter application to pasture, hay yields (as estimated by EPIC) do decrease resulting in a reduction in income of $562. However, in reducing litter application, 374 tons of excess litter are sold to other areas producers resulting in an increase in income of $7,480.

In addition to changes in litter handling, the producer also began to compost poultry carcasses rather than incinerate them. Therefore, the decrease in costs associated with incineration must also be included. The total annual cost of incineration is estimated at $3,639. The net change in income is + $7,249 indicating that nutrient management plan has increased income.

Table 3.14: Economic Impact of Nutrient Management Plan, Farm 4[a]

Additional Costs	Reduced Income	Additional Income	Reduced Costs	Net Income Change
$3308	$562	$7480	$3639	$7249

[a] Details of the budget are included in Table D.8.

Summary

The adoption of nutrient management practices result in significant reductions of potential nitrogen losses (as estimated by EPIC) from each of the case farms. Average annual per acre reductions in nitrogen loss range from 23 to 45 percent while net farm income increases from $395 to $7,249 (see Table 3.15). The increases in farm income are primarily the result of reductions in commercial fertilizer expenses resulting from crediting animal wastes for nutrient content. However, the highest increase in farm income ($7,249) is seen on Farm 4, the Piedmont Poultry, where the producer is able to sell excess poultry litter resulting from a reduction in the application rate. While Farm 4 has the highest increase in farm income, this farm also has the lowest initial nitrogen losses and the lowest reduction in nitrogen losses with the adoption of the nutrient management plan. Farm 4 consists entirely of rotationally grazed pasture while all other farms have little or no pasture affected by nutrient management planning. Nitrogen losses associated with pasture are generally lower than those associated with cropland (Scharf and Alley). Also, poultry litter was not concentrated on a small area of the farm prior to the adoption of the plan. Rather, litter was applied equally to all pasture.

Table 3.15: Summary of Case Farm Results

Case Farm	N App. Reduction (lb./ac)	N App. Reduction (%)	Average N Loss Reduction (lb./ac)	Average N Loss Reduction (%)	Range of N Loss Reduction (%)	Income Change
Farm 1	23	20	12.8	27	19 to 40	+$395
Farm 2	95	47	20.4	33	4.8 to 50	+$3563
Farm 3	39	41	18.5	45	-5.5 to 77	+$473
Farm 4	51	29	4.9	23	12 to 29	+$7249

With the exception of Farm 4, higher reductions in nitrogen loss are achieved on farms that did not have manure storage facilities prior to the adoption of the plan. On Farms 2 and 3, the installation of storage facilities allowed the producer to store animal wastes until application would be most beneficial to crops. In addition, storage allowed the producers to apply manure to much larger areas of cropland after the adoption of the plan. These changes in manure application practices allowed for significant reductions of commercial fertilizer applications.

The highest reduction in average annual nitrogen losses (45 percent) is seen on Farm 3, the Southeastern Virginia Crop and Swine Farm. The high reduction seen on this farm in comparison to the other case farms is a result of extremely high applications of swine manure to limited cropland before the adoption of the nutrient management plan (see Table 3.8). This high application results in correspondingly high nitrogen losses (see Table 3.10). The reduction of total plant available nitrogen applications on this cropland results in a reduction of nitrogen losses by 35 to 52 pounds per acre (a 61 to 77 percent reduction), depending on soil and slope. These reductions in nitrogen loss correspond to a reduction in nitrogen application (to land receiving manure prior to the plan) by an annual average of 121 pounds per acre (see Table 3.8).

Reductions in nitrogen loss (pounds) on all four case farms are much smaller than reductions in nitrogen applications. For example, on Farm 3, average annual plant available nitrogen applications are reduced by 24 pounds per acre while average nitrogen losses are reduced by less than 14 pounds per acre. Similar results have also been found by other studies such as that conducted by Hall and Risser. Hall and Risser found nitrogen losses were reduced 8 to 32 percent for corresponding reductions of 39 to 67 percent in nitrogen fertilizer applications.[20]

While the reduction in nitrogen losses varies across farms, the variation in nitrogen loss reductions within farms is more pronounced. For example, the Shenandoah Valley Dairy has nitrogen loss reductions ranging from 5 to 50 percent depending on soil and crop rotation. This farm has a good quality soil, Frederick, and a very poor quality soil, Nixa. Nixa soil is extremely gravelly and not very productive. Nitrogen losses both before and after the adoption of the nutrient management plan are 1.7 to 4.7 times higher on the Nixa soil in comparison to those seen on the Frederick soil with identical slopes and crop rotations (see Table 3.6). The higher losses on the Nixa soil are a result of the high levels of nitrogen loss through percolation (see Appendix B). However, nutrient reductions resulting from the adoption of the plan are also much higher on the Nixa soil than the Frederick soil. Percentage reductions in nitrogen loss on the Nixa soil are at least twice as high as reduction seen on Frederick soil. For example, in the corn, wheat, clover cover rotation, nitrogen losses on the Frederick soil with a 10.5 percent slope are reduced by 21 percent while losses from the Nixa soil with a 10.5 percent slope are reduced by 48 percent (see Table 3.6).

While soil type impacts nutrient losses, the slope of the soil also has an impact. On all case farms (excluding pasture on Farm 2), as slope increases, the percentage reduction in nitrogen losses decreases while the actual reduction in pounds per acre increases. This can be seen by examining the results on Farm 1, the Southwestern Virginia Dairy (see Table 3.2). On the Frederick soil with a 4.5 percent slope, a 39 percent reduction in nitrogen loss is achieved while a 29 percent reduction in nitrogen loss is achieved on the 10.5 percent slope. This trend is also observed on the Groseclose soil where a 38 percent reduction is seen on the 4.5 percent slope while a 28 percent reduction is seen on the 10.5 percent slope and a 21 percent reduction is seen on the 16.5 percent slope. After the implementation of the plan, the amount of nitrogen loss remains far higher on the steepest slopes.

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[20] For further explanation of Hall and Risser study, see Chapter 2.

Impact on Nutrient Management on Phosphorus Losses

While nutrient management planning results in significant reductions in nitrogen losses, phosphorus losses are also reduced from all farms with the exception of Farm 1, the Southwestern Virginia Dairy (see Table 3.16). No reduction is seen in phosphorus losses from this farm because no changes were made in the application rates of manure or commercial phosphorus as a result of the nutrient management plan. On all other farms, manure application rates were altered with the construction of manure storage facilities. On Farms 2 and 3, phosphorus applications to small grains were eliminated with the application of manure to cropland. On Farm 3, the Southeastern Virginia Crop and Swine, commercial phosphorus applications were also eliminated with the application of manure to cropland. As a result, phosphorus losses are reduced. On farm 4, the Piedmont Poultry, litter application to all pasture was reduced resulting in a reduction in phosphorus applications. On these farms, average phosphorus losses are reduced by up to 66 percent (see Table 3.16).

Table 3.16: Average Per Acre Phosphorus Losses (lb.) for Case Farms

Case Farm	Before Plan	After Plan	Percentage Reduction
Farm 1	6.9	6.9	0
Farm 2	12.5	10.4	17
Farm 3	2.5	0.9	66
Farm 4	7.6	5.5	28

Implications of Case Farm Analyses for Empirical Model

While case farm results suggest that significant reductions in nitrogen losses have been achieved through the implementation of nutrient management plans on Virginia livestock farms without decreasing farm income, it is unlikely that these reductions are adequate in achieving the goal of forty percent reduction in nitrogen loadings to the Chesapeake Bay. Further, it is unclear how farm income will be affected by further reducing nitrogen losses.

While the results suggest that there may be opportunities for improving reductions in potential nitrogen losses by targeting individual farms, the results of the case farm analyses show much greater variability in nitrogen loss reductions within farms (see Table 3.15). Average nitrogen loss reductions vary from 23 to 45 percent between farms while per acre reductions on Farm 2 vary from 5 to 50 percent. The variation in reductions across soils on Farm 3 are even more pronounced. These results suggest that opportunities do exist to reduce farm level nitrogen losses by planning at the farm level rather than the field level.

While highly excessive applications of fertilizers result in the highest losses, soil type, slope, and rotation appear to have a significant impact on the ability to reduce losses and the cost of achieving those reductions when identical practices are applied to the farm as a whole. It is possible that higher reductions may be achieved by targeting management practices within a farm based on farm physical characteristics such as soil type and slope. This possibility will be further explored in the development of a linear programming model to examine opportunities to further reduce nitrogen losses from Farm 2.

While the case studies suggest that potential nitrogen losses may be reduced through the implementation of nutrient management planning, these losses (and reductions in losses) do not necessarily represent loadings to ground and surface water. Nitrogen losses at the field level only represent potential loadings to water sources. Whether losses at the field level contribute to contamination of nearby water bodies will depend on numerous environmental characteristics of the area. Distance to water sources will impact whether field level losses contribute to pollution problems as field level losses can be absorbed by adjoining land areas or lost to the atmosphere.

Chapter 4: LP Model for Farm 2

Introduction

Methods for improving nutrient management planning at the farm level in order to achieve greater nitrogen loss reductions are evaluated using a linear programming model. The linear programming model will be developed for Farm 2, a dairy farm located in Augusta county. The variety of rotations, soils, and slopes present on the farm allows for examination of the possibility to reduce nutrient losses below current levels through alternative routing of manure and commercial fertilizers within the farm.

The overall purpose of the model is to examine methods for improving nutrient management planning at the farm level (rather than the field level) in order to achieve greater nitrogen loss reductions without decreasing farm profits. Therefore, only activities related to the nutrient management plan, such as the dairy operation, are included in the model. While the farm consists of approximately 1025 acres, the nutrient management plan applies to only 314 acres surrounding the dairy: 50 acres of permanent pasture, and 264 acres of cropland.

Model Set-up

The linear programming model maximizes returns minus variable costs subject to constraints on the amount of specific soils present on the farm, livestock numbers, feed ration requirements, manure use and pasture restrictions, and nitrogen loss:[21]

$$\text{Max} \; -\sum_{i=1}^{7}\sum_{j=1}^{42} c^1_{ij}ROT_{ij} - c^2DAIRY + \sum_{p=1}^{11} c^3_pSELL_p - \sum_{p=1}^{11} c^4_pBUY_p \quad (4.1)$$

subject to:

$$\sum_{j=1}^{42} ROT_{ij} \le SOIL_i \qquad \text{for } i = 1 \text{ to } 7 \qquad (4.2)$$

$$DAIRY \le 160 \qquad (4.3)$$

$$qDAIRY - DRY = 0 \qquad (4.4)$$

$$nDAIRY - HEIF = 0 \qquad (4.5)$$

$$-\sum_{i=1}^{7}\sum_{j=1}^{42} f_{pij}ROT_{ij} + u_p\,DAIRY + v_p\,DRY + w_p\,HEIF + SELL_p - BUY_p = 0 \qquad \text{for } p = 1 \text{ to } 11 \qquad (4.6)$$

$$-\sum_{i=1}^{7}\sum_{j=1}^{42} d_{mij}ROT_{ij} + w_mDAIRY = 0 \qquad \text{for } m = 1 \text{ to } 2 \qquad (4.7)$$

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[21] See Appendix E for entire model.

$$\sum_{i=1}^{7} \sum_{j=1}^{42} l_{kij}ROT_{ij} - LOSS_k = 0 \qquad \text{for } k = 1 \text{ to } 10 \qquad (4.8)$$

$$LOSS_{k=totalN} \leq RESTRICT \qquad (4.9)$$

where:

i = soils on farm in cropland and pasture
j = number of crop rotation, fertilizer management alternatives
c^1_{ij} = average annual cost of alternative per acre
ROT_{jij} = crop rotation, fertilizer management, soil type and slope combinations in acres
c^2 = annual cost of dairy cow excluding feed ration costs
DAIRY = dairy cows
p = farm products bought and sold on farm, including feed rations and milk produced
c^3_p = selling price of milk and excess crop production
$SELL_p$ = amount of crop (tons) and milk (cwt) sales
c^4_p = purchase price of feed rations (feed not home produced)
BUY_p = amount of crop purchases (tons) for feed rations
i = number of soils present on farm (three crop soils and four pasture soils)
$SOIL_i$ = maximum amount of each soil present on farm
q = limits dry cows in proportion to milk cows
DRY = dry cows
n = limits heifers in proportion to milk cows
HEIF = heifers
f_{pij} = amount of crop (p) produced on soil (i) in rotation (j) on soil (i)
u_p = amount of crop (p) consumed in tons by dairy cows annually
v_p = amount of crop (p) consumed in tons by dry cows annually
w_p = amount of crop (p) consumed in tons by heifers annually
m = type of manure, liquid or semi-solid
d_{mij} = amount of manure type (m) applied on soil (i) in rotation (j)
w_m = amount of manure type (m) produced per dairy cow
k = loss of pollutant (nitrogen, phosphorus, and soil) through individual pathways and as total
l_{kij} = loss of each pollutant from soil (i) for rotation (j)
$LOSS_k$ = total pollutant losses for farm
RESTRICT = nitrogen loss restriction for farm

All production functions in linear programming are linear and therefore exhibit constant returns to scale. Linear programming assumes there are no initial or start-up costs, and that each resource is used in proportion to the level of the activity. The linear production function represents production of a given level of output using a specific production process with specific levels of inputs. The inclusion of multiple alternative production methods (activities) allows the model to more closely approximate the continuous production function of neoclassical theory (Diebel). However, in linear programming the producer can select from only a finite number of activities.

Activities in the model are grouped into four general categories: 1) crop production (ROT_j), 2) accounting activities, 3) selling of farm products ($SELL_p$), and 4) purchase of farm products (BUY_p).

Crop production, in acres, is specified based on crop rotation, soil type, slope, and fertilizer management combinations. Three crop rotations in addition to pasture are currently followed on the portion of the cropland affected by the nutrient management plan: 1) corn, winter wheat, clover cover, 2) corn, barley double-cropped to soybeans, and 3) corn, barley, alfalfa. All corn, barley, and wheat production is chopped for silage. It is assumed in the model that no grain is produced on the modeled portion of the farm. While some fields planted in the corn, barley, soybean rotation are never planted to alfalfa, fields planted in alfalfa return to a corn, barley, soybean rotation after alfalfa is removed. Fields planted to alfalfa remain in alfalfa for seven years. Prior to the adoption of the nutrient management plan, four different rotations were followed: 1)corn, rye cover, 2) corn, barley, sudex hay, 3) corn, barley, corn, rye cover, and 4) alfalfa in rotation with corn, barley, sudex.

Both nutrient loss and crop yields are affected not only by weather conditions and management practices, but also by soil type. Therefore, each crop rotation / alternative combination is modeled on Frederick and Nixa soils. These soils are the predominant soils present on the farm and possess similar soil characteristics to the small amounts of other soils present. The Frederick soil is present on the farm in slopes ranging from B (2 to 7 percent) to E (25 to 45 percent). Nixa soil is present in B (2 to 7 percent) and C (7 to 15 percent) slopes. To represent these slope classifications, each crop rotation is modeled with EPIC on Frederick soil with a 4.5 and 10.5 percent slopes, and Nixa soil with a 4.5 percent slope. Pasture is modeled on Frederick soil with 4.5, 10.5, 16.5, and 26.5 percent slopes. The steeper slopes are not present in cropland. The soils and slopes were selected based on the soil survey of Augusta county and through consultation with soil scientists at Virginia Tech. The inclusion of multiple slopes and soils provides for a more realistic estimate of the impact of management practices on nutrient loss on this farm while also allowing for an examination of the impact farm physical characteristics may have on the effectiveness of farm level nutrient management. The first set of constraints, equation (4.2), included in the model limit the maximum amount of each soil type and slope ($SOIL_i$) on the farm:

$$\sum_{j=1}^{42} ROT_{ij} \leq SOIL_i \qquad \text{for i = 1 to 7} \qquad (4.2)$$

The upper limits of these constraints are based on estimates obtained through examination of a soil survey of the farm (see Table 4.1). Total cropland is limited to the 264 acres currently affected by the nutrient management plan while pasture is limited to 50 acres. In the linear programming model, alternative rotations and management practices are selected individually for each soil and slope on a per acre basis. However, the farmer would not be able to target a specific soil as accurately as the model.

Table 4.1: Soils Present on Farm

Soil Type and Slope	Acres in Cropland	Acres in Pasture
Frederick, 4.5 % slope	92.4	5
Frederick, 10.5 % slope	145.2	20
Frederick, 16.5 % slope		5
Frederick, 26.5 % slope		20
Nixa, 4.5 % slope	26.4	

Dairy cow numbers (DAIRY) are allowed to vary subject to the constraint that the maximum number of cows on the farm is no greater than the current level:

$$DAIRY \leq 160 \qquad (4.3)$$

The upper limit for dairy cows is equivalent to the current level of 160 milk cows. Dry cow (DRY) and replacement heifer (HEIF) numbers must be proportional to milk cow numbers:

$$qDAIRY - DRY = 0 \qquad (4.4)$$

$$nDAIRY - HEIF = 0 \qquad (4.5)$$

Currently, heifer numbers vary from 70 to 100 at any given time. For the purpose of the model, it is assumed that when 160 milk cows are present on the farm, there will be 85 heifers. Linear programming assumes that all inputs and outputs be infinitely divisible. Therefore, in the model, it is possible to produce half a cow when this is clearly not possible in reality.

Buying (BUY_p) and selling ($SELL_p$) of feeds and milk in the model are dependent on the number of dairy livestock:

$$-\sum_{i=1}^{7} \sum_{j=1}^{42} f_{pij} ROT_{ij} + u_p\, DAIRY + v_p\, DRY + w_p\, HEIF + SELL_p - BUY_p = 0$$

$$\text{for } p = 1 \text{ to } 11 \qquad (4.6)$$

The amount of milk produced, pasture requirements, and feed ration requirements are specified on a per cow basis (equation 4.6). Feed ration requirements are specified in tons per cow per year for milk cows, dry cows, and heifers. Only part of feed ration requirements are produced on the farm including corn silage, barley silage, wheat silage, alfalfa hay, and soybeans. The amount of each crop (p) produced per acre in rotation/alternative (j) is dependent on the soil (i) and fertilizer management alternative. Most crop production is accounted for in tons per acre. However, soybean yield is in bushels per acre and converted to tons for feed ration requirements. Any part of the feed rations not produced on the acreage modeled is assumed to be purchased (BUY_p) while any excess crop production is sold ($SELL_p$). All crop sales and purchases are in tons. Also, all milk is sold. Milk production is specified by hundred weight per cow per year. Feeds not produced on the acreage modeled will be purchased. This includes corn grain, barley grain, distillers grain, and minerals. The model also has the option to purchase soybeans or alfalfa if enough is not produced to meet feed ration requirements. Excess production of corn silage, barley silage, wheat silage, alfalfa hay, or soybeans above what is required to meet feed requirements is sold. Feed requirements are based on current feed rations used on the farm (see Table 4.2). The yearly requirements for dairy cows are based on the assumption that the cows will be dry 60 days per year. The pasture constraint is based on current livestock numbers in comparison to the pasture included in the model. It is assumed that if livestock numbers decline, the amount of continuously grazed pasture will also decline.

Milk cows are fed a corn silage/alfalfa hay based ration while winter replacement cows and dry cows are fed a barley or wheat silage ration. Dry cows and heifers are on pasture from April to October. Heifers also receive some barley grain during this time. The remainder of the year, heifers are on a feed ration which includes barley or wheat silage, poultry litter, and corn grain. In developing the feed ration requirements for heifers, three individual rations were developed for heifers of weights equivalent to 400, 800, and 1,200 pounds through consultation with dairy scientists at Virginia Tech. It is assumed in the model that a third of the heifers would be on each ration at any one time. Therefore, the heifer ration used in a model is an average for the three individual rations.

Table 4. 2: Livestock Feed Rations

	Dairy cows		**Dry cows**		**Heifers**	
Feed	lb./cow/day	tons/cow/year	lb./cow/day	tons/cow/year	lb./cow/day	tons/cow/year
corn silage	50.00	7.63				
soft dough barley/wheat silage			48.00	4.39	39.33	3.60
alfalfa hay	13.00	1.98				
corn grain	9.40	1.43			3.75	0.34
barley grain	3.00	0.46			3.50	0.32
soybean	4.00	0.61				
distillers grain	4.50	0.69				
broiler litter					3.83	0.35

In the model, the amount of manure produced in any given year is linked to the number of dairy cows on the farm during that year. Both liquid and semi-solid manure are produced. Manure production is specified on a wet basis. Semi-solid manure is specified in tons while liquid manure is specified in thousands of gallons. Manure applications (d_{mij}) are subject to the constraint that all manure must be applied to the portion of the farm included in the model.

$$-\sum_{i=1}^{7} \sum_{j=1}^{42} d_{mij} ROT_{ij} + w_m DAIRY = 0 \qquad \text{for } m = 1 \text{ to } 2 \qquad (4.7)$$

It is assumed in the model that manure can not be stored for use the following year. While most of the manure currently used is in liquid form, a limited supply of semi-solid manure is collected from heifers and dry cows and applied to pasture. Therefore, a constraint is also included in the model to account for this manure.

A series of transfer rows are included in the model to provide information about crop rotation selection through the use of accounting variables. Accounting variables in the model document total crop yields, livestock numbers, manure production and use, commercial nitrogen fertilizer applications, manure nitrogen applications, total (plant available) nitrogen applications to cropland, total soil loss, phosphorus loss, and nitrogen loss.

Nutrient losses (nitrogen, phosphorus, and erosion), as estimated by EPIC, are accounted for through both individual loss pathways and summed as a total through the use of a series of transfer rows.

$$\sum_{i=1}^{7} \sum_{j=1}^{42} l_{kij}ROT_{ij} - LOSS_k = 0 \qquad \text{for } k = 1 \text{ to } 10 \qquad (4.8)$$

The individual nitrogen loss pathways reported in the model include nitrate loss with runoff, organic nitrogen loss with sediment, and mineral loss through subsurface flow and percolation. Although volatilization losses are also reported in the model, they are not included in total nitrogen losses. A constraint is included in the model to allow for the restriction of total farm level nitrogen loss to a specified level (RESTRICT).

$$LOSS_{k=totalN} \leq RESTRICT \qquad (4.9)$$

When limiting total nitrogen losses, the inclusion of accounting activities for the individual nitrogen loss pathways will allow for a determination of where the reductions are being achieved.

Management Alternatives

Thirteen management alternatives, including the opportunity to remove land from production, are included in the model for cropland (see Table 4.3). These alternatives were selected in consultation with economists and soil scientists at Virginia Tech and nutrient management specialists and program managers from the Division of Soil and Water Conservation. Generally, total plant available nitrogen applications are kept constant through the alternatives examined with a few exceptions. Three alternatives result in higher or lower nitrogen application: 1) 9,000 gallons manure, 2)12,000 gallons manure, and 3) increased commercial fertilizer to corn. Tillage remains the same throughout all the alternatives modeled. Corn and legumes are planted no-till. No manure is applied to soybeans, clover, or alfalfa. Alternatives one, two, and three are included in the model to provide baseline estimates of nitrogen loss in examining management alternatives. Alternatives four through thirteen provide management options that can be selected to meet restrictions placed on farm level nitrogen loss. Fertilizer applications are explained in Tables 4.4 and 4.5.

The first alternative for cropland includes crop rotations and management practices utilized before the adoption of the initial nutrient management plan.[22] A few changes have been made in crop rotations for this alternative. Prior to the adoption of the nutrient management plan, four crop rotations were followed: 1) corn, rye cover, 2) corn, barley, sudex hay, 3) corn, barley, corn, rye cover, and 4) corn, barley, sudex in rotation with alfalfa. Practices followed before the adoption of the nutrient management plan include the application of manure on only the few fields closest to the dairy barn in addition to high commercial fertilizer applications. Manure was not credited for nutrient content. Fields with manure applications received the same amount of commercial fertilizer as other fields. Due to the higher cost of production resulting from high fertilizer applications, it is not expected that this alternative will be chosen by the model. Rather, the inclusion of these practices in the model is useful in illustrating the benefits of the nutrient management plan when the model is constrained to using these practices.

[22] For explanation of manure application rates used prior to the adoption of the nutrient management plan, see Appendix H.

Table 4.3: Definitions of Alternative Management Practices

No.	Name	Definition
(1)	BEFCBX	Corn, barley, sudex rotation before adoption of nutrient management
(1)	BEFCRCB	Corn, rye cover, corn, barley rotation before nutrient management
(1)	BEFCBA	Corn, barley, alfalfa rotation before nutrient management
(1)	BEFCR	Corn, rye cover before nutrient management
(2)	AFTCBS	Corn, barley, soybean rotation after nutrient management (current practices)
(2)	AFTCBA	Corn, barley, alfalfa after nutrient management (current practices)
(2)	AFTCWC	Corn, wheat, clover cover rotation with current management practices
(3)	HIGHNCBS	Corn, barley, soybean rotation with higher application of nitrogen to corn than current practices (commercial nitrogen only)
(3)	HIGHNCBA	Corn, barley, alfalfa with high commercial nitrogen application to corn
(3)	HIGHNCWC	Corn, wheat, clover with high commercial nitrogen application to corn
(4)	RYECBS	Corn, barley, soybean rotation with rye cover after soybean harvest
(4)	RYECBA	Corn, barley, alfalfa rotation with rye cover after soybean harvest
(5)	FALLCBS	Corn, barley, soybean with manure applied to corn the fall prior to planting
(5)	FALLCBA	Corn, barley, alfalfa with manure applied to corn the fall prior to planting
(5)	FALLCWC	Corn, wheat, clover with manure applied to corn the fall prior to planting
(6)	CBS9	Corn, barley, soybean with 9,000 gallons manure applied to corn and barley
(6)	CBA9	Corn, barley, alfalfa with 9,000 gallons manure applied to corn and barley
(6)	CWC9	Corn, wheat, clover with 9,000 gallons manure applied to corn and wheat
(7)	CBS12	Corn, barley, soybean with 12,000 gallons manure applied to corn and barley
(7)	CBA12	Corn, barley, alfalfa with 12,000 gallons manure applied to corn and barley
(7)	CWC12	Corn, wheat, clover with 12,000 gallons manure applied to corn and wheat
(8)	CBS3	Corn, barley, soybean with 3,000 gallons manure applied to corn and barley
(8)	CBA3	Corn, barley, alfalfa with 3,000 gallons manure applied to corn and barley
(8)	CWC3	Corn, wheat, clover with 3,000 gallons manure applied to corn and wheat
(9)	NOMANCBS	Corn, barley, soybean rotation with no manure application
(9)	NOMANCBA	Corn, barley, alfalfa rotation with no manure application
(9)	NOMANCWC	Corn, wheat, clover cover rotation with no manure application
(10)	SPLTNCBS	Corn, barley, soybean rotation with split commercial nitrogen, no manure
(10)	SPLTNCBA	Corn, barley, alfalfa rotation with split commercial nitrogen, no manure
(10)	SPLTNCWC	Corn, wheat, clover cover rotation with split commercial nitrogen, no manure
(11)	PLT30CBS	Corn, barley, soybean rotation with 30 lb. nitrogen applied to corn at planting
(11)	PLT30CBA	Corn, barley, alfalfa rotation with 30 lb. nitrogen applied to corn at planting
(11)	PLT30CWC	Corn, wheat, clover rotation with 30 lb. nitrogen applied to corn at planting
(12)	AUTOCBS	Corn, barley, soybean rotation with fertilizer applied by EPIC as needed
(12)	AUTOCBA	Corn, barley, alfalfa rotation with fertilizer applied by EPIC as needed
(12)	AUTOCWC	Corn, wheat, clover cover rotation with fertilizer applied by EPIC as needed
(13)	IDLECROP	Idle cropland, planted to a fescue - clover cover
(1)	BEFPAST	Pasture before nutrient management planning
(2)	AFTPAST	Pasture after nutrient management (current practices)
(3)	MANPAST	Pasture with manure only
(4)	COMMPAST	Pasture with only commercial fertilizer
(5)	IDLEPAST	Idle pasture

Table 4.4: Alternative Management Practices for the Corn, Barley, and Soybean (CBS) and the Corn, Barley, and Alfalfa (CBA) Rotations

Alternative/Rotation	Description
1) BEFCBX BEFCRCB BEFCBA	16 tons semi-solid manure to barley and sudex (BEFCBX only) 150 lb. (BEFCRCB and BEFCBA) - 160 lb. (BEFCBX) commercial nitrogen to corn 110 lb. commercial nitrogen to barley 80 lb. commercial nitrogen to sudex
2) AFTCBS AFTCBA	6000 gallons manure to corn and barley prior to planting 60 lb. commercial nitrogen to corn at planting 50 lb. commercial nitrogen to barley in March
3) HIGHNCBS HIGHNCBA	160 lb. commercial nitrogen to corn 30 lb. commercial nitrogen to barley at planting, 80 lb. nitrogen in early March
4) RYECBS RYECBA	Current practices with rye cover crop after soybean harvest
5) FALLCBS FALLCBA	6000 gallons manure to corn in fall (after soybean harvest) 6000 gallons manure to barley prior to planting 60 lb. commercial nitrogen to corn at planting 50 lb. commercial nitrogen to barley in March
6) CBS9 CBA9	9000 gallons manure to corn prior to planting 4500 gallons manure to barley prior to planting, 4500 gallons in early March 25 lb. commercial nitrogen to corn at planting
7) CBS12 CBA12	12000 gallons manure to corn prior to planting 6000 gallons manure to barley prior to planting, 6000 gallons manure in early March no commercial fertilizer
8) CBS3 CBA3	3000 gallons manure to corn and barley 95 lb. commercial nitrogen to corn 80 lb. commercial nitrogen to barley
9) NOMANCBS NOMANCBA	130 lb. commercial nitrogen to corn 30 lb. commercial nitrogen to barley at planting, 80 lb. in early March
10) SPLTNCBS SPLTNCBA	60 lb. nitrogen to corn at planting, 70 lb. nitrogen to corn sidedressed in early June 30 lb. nitrogen to barley at planting, 40 lb. in early March, 40 lb. in early April
11) PLT30CBS PLT30CBA	30 lb. nitrogen to corn at planting, 100 lb. nitrogen to corn sidedressed in early June 30 lb. nitrogen to barley at planting, 40 lb. in early March, 40 lb. in early April
12) AUTOCBS AUTOCBA	Timing and rates of fertilizer applications decided by EPIC (application rate = 30 lb. per application, maximum total N per crop = 150 lb.)
13) IDLECROP	no fertilizer, cropland planted to fescue-clover cover

[a] Management of alfalfa does not change with any alternative.

Table 4.5: Alternative Management Practices for Corn, Wheat, Clover Cover (CWC) Rotation

Alternative/Rotation	Description
1) BEFCR	150 lb. commercial nitrogen to corn 40 lb. commercial nitrogen to rye cover
2) AFTCWC	6000 gallons manure to corn and barley prior to planting 40 lb. commercial nitrogen to corn at planting 50 lb. commercial nitrogen to wheat in March
3) HIGHNCWC	140 lb. commercial nitrogen to corn 30 lb. commercial nitrogen to barley at planting, 80 lb. in early March
5) FALLCWC	6000 gallons manure to corn in fall (after soybean harvest) 6000 gallons manure to barley prior to planting 40 lb. commercial nitrogen to corn at planting 50 lb. commercial nitrogen to wheat in March
6) CWC9	9000 gallons manure to corn prior to planting 4500 gallons manure to wheat prior to planting, 4500 gallons manure in early March 5 lb. commercial nitrogen to corn at planting
7) CWC12	12000 gallons manure to corn prior to planting 6000 gallons manure to wheat prior to planting, 6000 gallons manure in early March no commercial fertilizer
8) CWC3	3000 gallons manure to corn and barley 75 lb. commercial nitrogen to corn 80 lb. commercial nitrogen to barley
9) NOMANCWC	110 lb. commercial nitrogen to corn 30 lb. commercial nitrogen to barley at planting, 80 lb. in early March
10) SPLTNCWC	60 lb. nitrogen to corn at planting, 50 lb. nitrogen to corn sidedressed in early June 30 lb. nitrogen to barley at planting, 40 lb. in early March, 40 lb. in early April
11) PLT30CWC	30 lb. nitrogen to corn at planting, 80 lb. nitrogen to corn sidedressed in early June 30 lb. nitrogen to barley at planting, 40 lb. in early March, 40 lb. in early April
12) AUTOCWC	Timing and rates of fertilizer applications decided by EPIC (application rate = 30 lb. per application, maximum total N per crop = 150 lb.)
13) IDLECROP	no fertilizer, cropland planted to fescue-clover cover

The second alternative for cropland is management practices used after the implementation of the nutrient management plan. In this alternative, all cropland receives manure at the same application rate and total fertilizer application rates have been reduced across all crops. Liquid dairy manure is applied to all cropland at a rate of 6000 gallons per acre. Manure applied to cropland is credited for nutrient content and commercial fertilizer usage is reduced by 60 - 100 pounds per acre depending on crop and rotation. Application of commercial nitrogen to all small grains is reduced from 110 pounds per acre to 50 pounds per acre. Commercial nitrogen applications to corn are reduced from 150 - 160 pounds per acre to 40 - 60 pounds per acre, depending on rotation. Corn following clover receives 40 pounds per acre while corn following soybeans receives 60 pounds per acre. Prior to the plan, commercial phosphorus was applied to small grains at a rate of 50 pounds per acre. No commercial phosphorus is applied to crops at this time with the exception of alfalfa. Alfalfa receives no manure application.

Alternative three explores the environmental impact of applying more nitrogen to corn than is recommended when only commercial fertilizer is used. Once again, this alternative is not expected to improve the nutrient management plan, as total nitrogen application is increased over current practices, but is included to explore the increase in nutrient loss if a farmer were to apply a somewhat higher application of nitrogen to corn than is recommended.

The fourth alternative is the use of a rye cover after the harvest of soybeans. Currently, soybeans are harvested in late October or early November after which the field remains fallow until corn is planted the following spring. Under alternative four, a rye cover is planted immediately following soybean harvest and is killed immediately prior to the planting of corn. This alternative will only apply to the rotations in which soybean follows the harvest of small grains. It will not be used in the corn, wheat, clover rotation as the clover already provides a winter cover.

The fifth alternative includes application of manure to corn during the fall previous to planting rather than shortly before planting (the current practice). In the case of the corn, barley, soybean rotation, the manure will be applied immediately following the harvest of soybeans. In the corn, wheat, clover rotation, the manure will be applied as a topdress to the clover. This alternative is not aimed at exploring the possibility of improving the current nutrient management plan on farm 2, but is included to explore the environmental benefit of changing the timing of manure applications on farms where manure is being applied in the fall for convenience.

In order to examine the possibility of improving nutrient management planning by targeting specific soils, alternatives six through nine will allow the routing of manure and commercial fertilizer to specific soils and rotations at higher or lower application levels (compared to practices used after nutrient management). The sixth alternative included for cropland is an increase in manure applications by 3,000 gallons per acre per crop while the seventh alternative is an increase in manure application by 6,000 gallons per acre per crop. The eighth alternative is the reduction of manure application by 3,000 gallons per acre per crop. In altering the application rate of manure, commercial fertilizer applications are modified to reflect the change in nitrogen available to the crop from manure in order to keep total plant available nitrogen application to crops approximately constant[23]. Nitrogen availability from manure is calculated in Table 4.6 following procedures outlined in the Nutrient Management Handbook (Virginia Department of Conservation and Recreation, 1993).

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[23] See Tables 4.4 and 4.5 for application rates.

Although commercial fertilizer applications rates are varied to compensate for changes in manure applications, the increase in manure to 9,000 and 12,000 gallons of manure to corn and small grains results in some changes in total plant available nitrogen applications. In increasing the application of manure to 9,000 gallons, the total plant available nitrogen application to corn is kept constant. However, the application of nitrogen to small grains is reduced by approximately 20 pounds, because a farmer would not sidedress an application of nitrogen fertilizer of less than 30 pounds per acre. By splitting the manure application to small grains, the need for a commercial fertilizer application is eliminated. If commercial application is set at 30 pounds per acre, nitrogen application would be higher than current practices. By increasing the application of manure to 12,000 gallons, the application of total plant available nitrogen to both corn and small grains in the corn, barley, soybean rotations is increased by 10 pounds per acre. The application of plant available nitrogen to corn in the corn, wheat, clover cover rotation is increased by 30 pounds per acre.

Table 4.6: Nitrogen available to crops from liquid dairy manure[a]

Corn:	
NH_4= 13.23 lb./1000 gallons	13.23 * .45 = 5.95
Org. N = 12.62 lb./1000 gallons	12.62 * .35 = 4.42
residual	12.62 * .10 = 1.26
Total N avail / 1000 gallons	**11.63 lb.**
Barley and Wheat:	
NH_4 = 13.23 lb./1000 gallons	13.23 * .45 = 5.95
Org. N = 12.62 lb./1000 gallons	12.62 * .20 = 2.52
residual	12.62 * .10 = 1.26
Total N avail / 1000 gallons	**9.74 lb.**

[a] Nitrogen availability for corn is calculated for surface applied lagoon liquid to land receiving frequent past applications. Manure is applied in spring. Nitrogen availability for barley and wheat is calculated in same manner as for corn with the exception that organic nitrogen availability is based on winter application rather than spring or fall even though the application occurs before November 1. This is done to be conservative in estimates of plant available nitrogen as the farmer would undoubtedly be.

The ninth alternative includes using only commercial fertilizer to meet crop needs. Commercial application of nitrogen is set equal to the level of nitrogen currently applied in manure and commercial fertilizer. In alternative eight, all fertilizer is applied at the same times as current applications of manure and commercial fertilizer. All fertilizer is applied to corn at planting while fertilizer applied to small grains is split between a planting application and one spring application, roughly coinciding with growth stage thirty (see Tables 4.4 and 4.5). The ninth alternative (only commercial fertilizer) will allow for examination of the value of manure nutrients in meeting crop needs.

Alternatives ten through twelve explore the benefit gained from splitting nitrogen fertilizer applications, when all fertilizer is applied in commercial form. The rates of application at planting and as sidedress in alternatives ten and eleven are based on consultation with nutrient management specialists as to what might be recommended in a nutrient management plan. The twelfth alternative in the model is the use of the auto-fertilizer option contained in the EPIC model. With this option, the application rate and timing of fertilizer applications are based on the nitrogen stress of the crop, as determined by EPIC. The application rate is set at 30 pounds per acre per application with a maximum allowable application of 150 pounds per crop. The application rate of 30 pounds is based on consultation with nutrient management specialists, who stated that most farmers would not apply less than 30 pounds in any single application. However, EPIC may apply nitrogen after the time when a crop could normally be fertilized with field spreading equipment.

The final alternative allows for the removal of land from crop production as a means to further reduce nutrient losses. Land removed from production is planted to a fescue - clover cover. This cover was selected in consultation with soil scientists at Virginia Tech.

Pasture is modeled for five different alternatives (see Table 4.7). As with cropland, these alternatives were selected through consultation with Division of Soil and Water Conservation nutrient management specialists and program managers. All pasture is fescue.

As with cropland, practices used on pasture before nutrient management planning and current practices are both included in the model as alternatives. Prior to the adoption of the nutrient management plan (alternative one), semi-solid manure was applied to home pasture at a rate of 28 tons per acre.[24] After the plan, pasture receives approximately 5 tons per acre of semi-solid manure per year in addition to 40 pounds of commercial nitrogen applied in the spring. Once again, it is not expected that the model will choose practices used before the plan. However, the inclusion of these practices is useful in illustrating the benefits already achieved through nutrient management planning. The third alternative included for pasture is the use of a higher application of manure to meet the nutrient requirements of pasture without a supplementary application of commercial fertilizer. The fourth alternative in the model is the use of only commercial fertilizer to meet the needs of pasture. The amount of commercial fertilizer applied is equivalent to the assumed nutrient content of manure plus commercial fertilizer applied under pasture alternative 2. The inclusion of these last two alternatives allows for the examination of possible benefits associated with avoiding manure applications on slopes more susceptible to nutrient losses. The fifth alternative included is idle pasture. This alternative allows for pasture to no longer be grazed as livestock numbers are reduced.

Table 4.7: Alternative Management Practices for Pasture

Alternative	Description
1) BEFPAST	28 tons semi-solid manure
2) AFTPAST	5 tons semi-solid manure 40 lb. nitrogen in spring
3) MANPAST	13 tons semi-solid manure
4) COMMPAST	65 lb. nitrogen in spring
5) IDLEPAST	No fertilizer, no grazing

[24] For explanation of manure application rates used prior to the adoption of the nutrient management plan, see Appendix H.

Model Coefficients:

Costs of crop and livestock production are based on the Virginia Cooperative Extension Farm Management Enterprise Budgets (see Table 4.8). The cost of crop production is included as an average annual cost for the rotation. Modifications were made to budgets to better reflect farmer costs and practices. Budgets include cost estimates for seed, chemicals, and fertilizers. Variable costs of machinery associated with planting, harvest, and application of fertilizers and chemicals are also included in crop production budgets. No fixed costs are included. Differing crop production costs, within a single rotation, are due to changes in fertilizer application practices. All other costs for a rotation are unchanged throughout the alternatives examined. Dairy cow budgets include cost estimates of minerals, vitamins, veterinary services, medicines, DHIA, hauling milk, machinery, and labor. Although feed ration costs are accounted for individually in crop production or feed purchasing activities, the dairy cow budget does include an estimate for cost of grinding and mixing feed.

All crop rotations included in the model have been grown on the farm and it is assumed that adequate labor and machinery is available for any of the alternative practices. Since the alternatives examined entail little or no change in labor requirements, labor is not a constraint. However, while labor is not included as a constraint in the model, it is treated as a cash cost in the development of production budgets. Changes in labor requirements resulting from additional fertilizer applications are reflected in this manner. No fixed costs are included in the budgets with the exception of farmer - provided labor as described.

The cost of applying liquid dairy manure has been estimated through use of a custom hauling rate of $40 per hour and through consultation with the farmer. The cost of semi-solid manure application both before and after the plan is estimated based on farmer equipment costs and application time requirements. There is no adjustment in manure application costs to account for distance or timing of application. All available cropland for manure applications is within a distance of 1.5 miles from the manure pit. As a result, no significant change in hauling and application time results from varying distances of fields.

The cost of applying commercial fertilizer is estimated at $4.80 per acre per application. This estimate is obtained from the Virginia Cooperative Extension Farm Management Enterprise Budgets. Therefore, with EPIC's autofertilization option, the cost of fertilization application is computed by dividing the average nitrogen application per crop by the amount per application (30 pounds) times the cost per application.

It is assumed in the model that no maintenance costs are associated with idle crop or idle pasture once the cover is established. While in some years it may be necessary to engage in some weed control to maintain a good grass cover, it is unlikely to be necessary on a yearly basis. In addition, the cost of weed control would be minimal. Therefore no cost is included in the model.

Prices for selling and purchasing activities included in the model were obtained from the farmer (see Table 4.9). All prices, with the exception of milk are in dollars per ton. The price for milk is in dollars per hundred weight. Although soybean production in the model is accounted for in bushels, feed ration requirements are specified by weight. Therefore, all soybean production is converted to tons using a weight of 60 pounds per bushel. Also, the price for soybeans obtained from the farmer is in dollars per ton. The price for selling alfalfa is low because excess alfalfa production is harvested by the producer making the purchase.

Table 4.8: Average annual cost for management alternatives[a]

Alternative/Rotation	Cost ($/acre)	Alternative/Rotation	Cost ($/acre)
BEFCBX	297	PLT30CWC	211
BEFCRCB	310	AUTOCWCFB[b]	213
AFTCBS	203	AUTOCWCFC[c]	213
RYECBS	216	AUTOCWCN[d]	206
FALLCBS	203	BEFCBA	253
CBS9	201	AFTCBA	220
CBS12	208	RYECBA	226
CBS3	205	FALLCBA	220
NOMANCBS	220	CBA9	219
HIGHNCBS	224	CBA12	223
SPLTNCBS	225	CBA3	222
PLT30CBS	225	NOMANCBA	229
AUTOCBSFB[b]	226	HIGHNCBA	230
AUTOCBSFC[c]	229	SPLTNCBA	231
AUTOCBSN[d]	224	PLT30CBA	231
BEFCR	264	AUTOCBAFB[b]	234
AFTCWC	189	AUTOCBAFC[c]	234
FALLCWC	189	AUTOCBAN[d]	232
CWC9	187	IDLECROP	0
CWC12	197	BEFPAST	218
CWC3	193	AFTPAST	81
NOMANCWC	206	MANPAST	121
HIGHNCWC	210	COMMPAST	63
SPLTNCWC	211	IDLEPAST	0

[a] For description of alternatives, see Tables 4.4 and 4.5.
[b] FB - Frederick Soil, 4.5 % slope
[c] FC - Frederick Soil, 10.5 % slope
[d] N - Nixa Soil, 4.5 % slope

Table 4.9: Feed Prices

Product	Sale Price[a]	Purchase Price[a]
Corn silage	25	
Barley silage	19	
Wheat silage	19	
Sudex hay	70	
Alfalfa hay [b]	50	110
Soybeans	240	266
Corn grain		175
Barley grain		117
Distillers grain		190
Broiler litter		15
Milk ($/cwt.)	13	

[a] Price is dollars per ton unless otherwise noted.
[b] Price is lowered because buyers assume responsibility for harvest and transport.

Estimating Crop Yields and Nutrient Losses with EPIC

The changes in crop yields and nutrient losses under the selected management practices are estimated with EPIC. EPIC results (annual averages) for all alternatives are included in Appendix F. For this project, the model is calibrated by comparing EPIC estimated average yields under current and previous management practices to those obtained by the farmer. Also, all results were examined by a soil scientist at Virginia Tech to determine if estimates provided by EPIC for yields and nutrient losses were realistic.

Necessary data for modeling of current and alternative practices were collected through evaluation of the farm nutrient management plan, consultation with the appropriate nutrient management specialist, and interviews with the producer. Values used in EPIC for nutrient content of liquid manure are based on an average of nutrient values obtained from manure tests for the farm over the period of April 1988 to May 1995. Nutrient values used for semi-solid manure were obtained from the Nutrient Management Handbook because no test results were available from the farm. These values are average values for semi-solid beef manure tested in Virginia during the period of January 1989 to November 1992. Manure nutrient content values are shown in Table 4.10.

Table 4.10: Manure Nutrient Content

Manure Type	TKN	NH_4	P_20_5	% MOISTURE
Liquid Dairy Manure[a]	25.85	13.23	12.23	93.92
Semi-solid Manure[b]	12.79	2.57	6.67	73.08

[a] Nutrient values are in pounds per 1000 gallons.
[b] Nutrient values are in pounds per ton.

Each combination of soil type, crop rotation, and management practice is modeled for a period of fourteen years, the length of the longest rotation. The use of fourteen-year simulations allows EPIC to account for the build-up of nutrients in the soil over a prolonged time period. Also, initial levels of nitrogen and phosphorus are adjusted for all soils to reflect any build-up of nutrients in the soil from prolonged use of manure. A warm-up period of six years is simulated with EPIC to estimate this build-up. The warm-up of six years was selected because the manure pit was constructed six years ago and it can be expected that nutrient build-up in most soils which had not previously received manure started at that time. Current manure application practices were established at the time of the construction of the manure pit. The ending levels of nitrogen and phosphorus in the soil at the end of the warm-up simulations, as reported by EPIC, are then used as starting values in all fourteen year simulations.

Each fourteen-year simulation is run one hundred times using randomly generated weather. The weather pattern for each simulation is generated by EPIC using parameters established for Augusta county. The parameters were created using actual daily weather data for Augusta county during the period of 1953 to 1993. Although the weather created by EPIC for each of the one hundred simulations is different, the long-term statistical properties of the weather parameters are maintained. In addition, while each of the 1,400 years of weather is different, each alternative uses the same 1,400 years of weather. This allows for comparison of results without the need to consider changes in yields or nutrient loss due to variation in weather. The coefficients in the linear programming model for crop yields and nutrient losses are the average of 100 14-year averages. While the linear programming model chooses alternative management practices based on annual averages for crop yields and nutrient losses estimated by EPIC, the distribution of yields and nitrogen losses under current and previous management practices will be tested for normality using a Kolmogorov-Smirnov test. These normality tests are used to determine whether the means of EPIC estimated crop yields and nutrient losses are a reasonable representation of the center of the distributions. The results of these tests are included in Appendix G. Normality could not be rejected for EPIC estimated distributions of crop yields and losses.

Linear programming assumes that the values of all parameters, such as crop yields, nutrient losses, and costs, affecting the producer's decision are know to the producer before a decision is made. In reality, while the producer may be able to roughly estimate changes in crop yields under alternative management practices, yields can not be known with certainty due to uncertainty about weather or nutrient availability. The producer is less likely to make an accurate prediction of changes in nutrient losses with alternative fertilizer management practices. However, the model may select alternative management practices based on slight differences in crop yields, costs, or nutrient losses that a producer is unable to estimate.

Scenarios to be Run

Several alternatives are examined with the linear programming model (see Table 4.11). First, the model is restricted to the management practices followed prior to the adoption of the nutrient management plan. Second, the model is restricted to the crop rotations and fertilizer practices followed after the plan on the farm. Restricting the model to these two alternatives will illustrate the benefits, in terms of reduced nutrient loss, already achieved through the implementation of nutrient management planning and the cost of those reductions. The farm level losses estimated under current practices will also be used as a base of comparison for all other scenarios examined.

Next, selection of crop rotations and fertilizer management alternatives is flexible. It is not expected that the model will select current fertilizer practices and rotations (after the nutrient management plan). The nutrient management plan was not developed with the purpose of maximizing net economic return. Rather, nutrient management planning is based on the objective of keeping nutrient applications on all cropland at or below agronomic recommendations. While the costs of most alternatives examined in the model are generally higher than those estimated for current practices, the change in fertilizer practices does result in some increases in crop yields which may increase farm income enough to compensate for an increase in cost. Also, the amount of cropland devoted to each crop rotation is at least partly due to farmer preference. In addition, the farmer does not currently sell soybeans. Soybeans are grown strictly to meet feed ration requirements. In the model, excess soybean production can be sold which may encourage more soybeans being planted than current levels.

Multiple runs will be made to examine a whole-farm restriction on nitrogen loss. This will be done to see if higher nitrogen loss reductions can be achieved than those currently achieved. Results from studies discussed in Chapter 2 suggest that it is possible to achieve significant reductions in nitrogen losses by adopting best management practices. However, the degree of the reduction achieved and the impact on farm income clearly depend on farm characteristics. While some studies have examined the varying impacts of nutrient management practices across soils and slopes, examination generally is limited to practices applied across the whole farm. One area that has been overlooked is the possibility of reducing farm level nitrogen losses by alternative routing of manure/fertilizer within a single farm. Currently, nutrient management planning limits the application of nutrients within a particular field to crop requirements. However, it may be possible to achieve higher reductions at the farm level through the higher applications of nutrients (particularly from manure) on those soils and slopes less susceptible to nutrient losses. Increased nutrient losses on such fields may be more than offset by reductions on soils more susceptible to nutrient losses. Once a base level of nitrogen loss is found by limiting the model to current practices, total nitrogen loss restriction will be varied parametrically while the model is free to choose among any alternative.

Next, the model will be restricted to the mix of crop rotations currently produced on the farm while fertilizer management practices are flexible. Initially nitrogen loss will be unrestricted. However, as when crop rotations are flexible, nitrogen loss will be varied parametrically to determine how far nitrogen losses can be reduced without changing crop rotations or removing land from production.

Sensitivity Analysis

Sensitivity analysis will be conducted to determine how costs of achieving nitrogen loss reductions will be impacted by several changes in the model. First, the most likely change to occur on the farm in the future is an increase in the number of dairy cows. Therefore, the number of livestock on the farm will be increased by 10 and 20 percent. The increase in livestock numbers will result in an increased volume of manure that must be utilized. Finally, the price of milk will be increased and decreased by 25 percent. In the model, a price of $13.00 per hundred weight is used. However, the price of milk will change over time and may impact the choice in method for achieving nitrogen loss restrictions.

Table 4.11: Linear programming model scenarios

Scenario	Description
Before plan	Crop rotations and fertilizer management practices restricted to those used before the adoption of the nutrient management plan.
After plan	Crop rotations and fertilizer management practices restricted to those used after the adoption of the nutrient management plan.
Nitrogen loss scenario with flexible rotations and fertilizer management practices	Crop rotations and fertilizer management practices are selected by the model so as to maximize farm net economic return. Nitrogen loss constraint is varied parametrically.
Nitrogen loss scenario with restricted rotations	Crop rotations are restricted to rotations followed after the adoption of the nutrient management plan while fertilizer management practices are selected by the model. Nitrogen loss constraint is varied parametrically.
Increased livestock numbers	The number of livestock is increased by 10 and 20 percent. Crop rotations and fertilizer management practices are flexible.
Change in milk price	Milk price is increased and decreased by 25 percent. Crop rotations and fertilizer management practices are flexible.

Chapter 5: Farm 2 Model Results

This chapter presents the results of the linear programming model developed for Farm 2, the Shenandoah Valley Dairy. EPIC simulation results provide estimated crop yields, erosion losses, phosphorus losses, and nitrogen losses for the farm. First, the impact of individual alternatives on nitrogen losses at the field level as estimated by EPIC will be discussed. Next, the results of nitrogen loss scenarios examined for Farm 2 using the linear programming model will be discussed. The alternative scenarios examined include a restriction to management practices used before the adoption of the nutrient management plan, a restriction to practices used after the plan, an unrestricted scenario, and several scenarios limiting nitrogen loss from the farm. Finally, results of the sensitivity analysis will be discussed.

Field Level Nitrogen Losses with Alternative Management Practices

In general, the adoption of nutrient management practices (AFTCBS, AFTCBA, and AFTCWC) results in a reduction of nitrogen losses from soils receiving manure prior to the adoption of the plan (BEFCBXFB, BEFCBXFC, BEFCBXN, AND PASTURE)[1]. Crop yields and nitrogen losses for all alternatives are listed in Tables F.2 through F.5.[2] The highest reductions in nitrogen loss with the adoption of the plan occur on pasture. These soils received high applications of manure prior to the adoption of the plan while pasture contains steep slopes.[3]

Land not receiving manure prior to the adoption of the nutrient management plan generally had constant or increased nitrogen losses with the adoption of the nutrient management plan. The addition of manure to these fields increased organic nitrogen losses by more than other nitrogen losses decreased with the reduction in commercial fertilizer. The exception to this trend is the Nixa soil (BEFCRCBN and BEFCBAN). On this soil, losses of mineral nitrogen with percolation are significantly reduced with the reduction in commercial fertilizer applications (AFTCBSN and AFTCBAN). These reductions are larger than the increases in organic nitrogen losses.

Within an individual crop rotation, lower nitrogen losses are seen for alternatives in which no manure is used in comparison to an alternative in which manure is utilized. For example, land in the corn, barley, soybean rotation with practices used after the nutrient management plan (AFTCBSFB) has total nitrogen loss of 24 pounds per acre while land in the same rotation receiving no manure (NOMANCBSFB) has an estimated total nitrogen loss of 20 pounds per acre (see Table F.2). The only exception to this trend is when commercial nitrogen is applied at a higher rate than nitrogen is currently applied using manure (HIGHNCBSN, HIGHNCWCN, and HIGHNCBAFB; see Tables F.2, F.3, and F.4). The smallest nitrogen losses occur when fertilizer is applied by EPIC in 30 pound increments as needed by the crop (alternative thirteen). With this alternative management practice on the Frederick soil with a 4.5 percent slope, nitrogen losses are 16 pounds per acre from land in the corn, barley, soybean rotation (AUTOCBSFB)

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[1] Alternatives are defined in Table 4.3. Each alternative for cropland is modeled on three soils. FB refers to Frederick soil with a 4.5 % slope, FC refers to Frederick soil with a 10.5 % slope, and N refers to the Nixa soil.
[2] A more detailed explanation of all alternatives is included in Chapter 4.
[3] See Appendix H for explanation of manure applications prior to adoption of the plan.

Increasing manure applications (in comparison to current applications) by 3,000 and 6,000 gallons per acre results in increased losses from all soils (alternatives six and seven). On the Frederick soil with a 10.5 percent slope, total estimated nitrogen loss from the corn, wheat, clover rotation when 6,000 gallons of manure are applied (AFTCWCFC) is 50 pounds per acre. When manure application is increased to 12,000 gallons (CWC12FC), nitrogen loss increases to 61 pounds per acre. The increase is predominantly associated with increased organic nitrogen losses with sediment. Decreasing manure applications by 3,000 gallons per acre while increasing commercial nitrogen applications (CWC3FC) reduces nitrogen losses to 45 pounds per acre.

Planting a rye cover crop after the harvest of soybeans had little impact on nitrogen losses on the Frederick soils (RYECBSFB and RYECBSFC) while decreasing losses from the Nixa soil (RYECBSN). On the Nixa soil nitrogen losses are reduced by 7 pounds per acre (see Table F.2). This reduction is achieved primarily through a reduction in mineral nitrogen losses with percolation.

In comparison to the case farm analysis of Farm 2 presented in Chapter 3, the results of the long term simulations used for the linear programming model show that it is important to consider the long term build-up of nutrients in the soil when determining the best method for applying animal wastes to cropland and pasture. Case farm analysis simulations were conducted for a three year period while simulations for the linear programming model were fourteen year simulations. In the long term simulations the build-up of organic nitrogen in the soil results in much higher organic nitrogen losses from soil receiving manure applications. As a result, higher reductions in total nitrogen loss are achieved on soils receiving manure applications prior to adoption of the nutrient management plan. In addition, smaller reductions are achieved on soils receiving manure after the adoption of the plan when none was applied before nutrient management planning.

Restriction to Practices used Before and After Nutrient Management Planning

At the time of the adoption of the nutrient management plan, crop rotations were altered while total cropland was held constant.[4] The change of rotations introduced the use of legumes in all rotations. The amount of land in alternative rotations before and after the plan is shown in Table 5.1. With the adoption of the plan, both legumes and animal manures were credited for nutrient content resulting in a reduction of commercial fertilizer applications.[5]

With the adoption of the nutrient management plan, total nitrogen losses for the farm are reduced 34 percent while phosphorus losses are reduced 40 percent and erosion is reduced 16 percent (see Table 5.2). Farm net economic return increases by $9,644.

The increase in farm income is greater than the change in income indicated through the use of partial budget included in Chapter 3 for Farm 2. This difference occurs as a result of several factors. Since crop rotation changes were not a direct result of the nutrient management plan, changes in crop production costs (other than fertilizer costs) and total amounts of each crop produced were not considered in the partial budget analysis. In the partial budget analysis, the increase in farm return is due to the changes in manure and commercial fertilizer use with the implementation of the nutrient management plan. In the linear programming analysis, crop production budgets include cost estimates for seed and chemicals in addition to fertilizers. Variable

[4] To see the amount of each soil in crop rotations, see Appendix H.

[5] See explanation of management alternatives in Chapter 3 for further explanation.

costs of machinery associated with planting and harvest are also included. Another difference arises from the inclusion of feed rations for livestock in the linear programming model. Feed rations included in the linear programming model are based on crop rotations used after the plan. Therefore, when the model is restricted to rotations followed before the adoption of the nutrient management plan, all soybeans must be purchased. The cost associated with the purchase of soybeans is drastically reduced when rotations are restricted to those used after the adoption of the plan. For more detail concerning crop production and buying and selling activities, see Appendix H, Tables H.3 - H.6.

Table 5.1: Crop Rotation Selection Before and After Nutrient Management [a]

Crop Rotation	Acres Before Plan	Acres After Plan (Current Practices)
Corn, Rye Cover	52	
Corn, Barley, Sudex	38	
Corn, Rye, Cover, Corn, Barley	33	
Corn, Barley, (Sudex) Alfalfa	141	
Corn, Wheat, Clover Cover		52
Corn, Barley, Soybean		71
Corn, Barley, (Soybean) Alfalfa		141
Continuously Grazed Pasture	50	50
Total	314	314

[a] See Appendix H for the amount of individual soils in each crop rotation.

Table 5.2: Summary Statistics for Before and After Nutrient Management Plan

Alternative	Net Economic Return ($)	Dairy Cows	Erosion (tons)	Total N Loss (lb.)	Total P Loss (lb.)	Manure N App.[a] (lb.)	Commercial N App. (lb.)	Total N App.[a] (lb.)
Before Plan	79968	160	2158	21812	5778	9368	37250	46618
After Plan	89612	160	1981	14468	3482	13777	12677	26453

[a] Plant available application.

The reduction in nitrogen loss from the farm is primarily due to a reduction in organic nitrogen loss (see Table 5.3). Although the addition of manure to cropland with the adoption of nutrient management results in higher organic nitrogen losses associated with cropland, this increase is more than offset by a reduction in organic nitrogen loss from pasture (see Appendix F). Prior to the adoption of the nutrient management plan, manure was applied to pasture at high application rates. In addition, pasture was poorly maintained (allowed no recovery time after grazing) while containing some very steep slopes. These factors combined resulted in very high organic losses (see Table F.5). The change in manure use on pasture results in significant reductions in organic nitrogen losses, particularly on the steeper slopes. For example, organic nitrogen losses from pasture with a 16.5 percent slope are reduced by 68 percent with the adoption of the nutrient management plan.

Generally, land in the corn, barley, soybean rotation has higher losses than land in the corn, wheat, clover cover rotation (see Tables F.2 and F.3). The lowest nitrogen losses are from land in the corn, barley, alfalfa rotation (see Table F.4) which remains in alfalfa for seven of the fourteen years modeled with EPIC. No manure or commercial nitrogen is applied to alfalfa. Before the adoption of the nutrient management plan, losses are highest from pasture (see Table F.5).

Table 5.3: Nutrient Losses (lb.) Before and After Nutrient Management

Loss Pathway	Losses Before Plan (lb.)	Losses After Plan (lb.)	Reduction (lb.)	Percentage Reduction
Nitrate Loss with Runoff	1188	1070	118	10
Organic N Loss w/ Sediment	15651	9989	5662	36
Mineral N w/ Subsurface Flow	1549	1228	321	21
Mineral N with Percolate	3426	2181	1245	36
Total N Loss	21812	14468	7344	34
Soluble P in Runoff	80	16	64	80
P Loss with Sediment	5698	3466	2232	39
Total P Loss	5778	3482	2296	40

Nitrogen Loss Scenarios with Flexible Rotations and Fertilizer Management

In examining possibilities for improving nutrient management, the model is free to choose any crop rotation or fertilizer management practice subject to the constraints that all manure must be applied to cropland or pasture, all land must be in production or be planted to a grass cover, and feed ration requirements of the livestock must be satisfied.[6] Initially, no constraint is placed on nitrogen losses from the farm. However, the nitrogen loss constraint is later varied parametrically to examine the impact of nitrogen loss restrictions on farm returns.

Nitrogen Loss Unconstrained

As expected, the model does not select fertilizer practices and rotations used after the nutrient management plan when unrestricted in management practice selection. When crop rotation and fertilizer management is flexible, the model keeps all cropland in the corn, barley, soybean rotation (see Table 5.4). Although this crop selection results in the need to purchase alfalfa hay, excess corn silage, barley silage, and soybeans above feed rations requirements are sold (see Table I.2).

In addition to selection of a different crop mix than is currently produced on the farm, the model also chooses varying application rates of manure (see Table I.1). Manure is applied to 123 acres of Frederick soil with 10.5 percent slope at a rate of 6,000 gallons per acre while all remaining cropland received 3,000 gallons per acre. Manure is applied to all pasture at a rate of 5 tons per acre. The change in application rates of manure to cropland occurs because when no land is in alfalfa, insufficient manure is available to apply the current application of 6,000 gallons per acre to all corn and small grains as is done after the adoption of the nutrient management plan.

[6] A more detailed explanation of model constraints is provided in chapter 4.

Table 5.4: Crop Rotation Selection in Nitrogen Loss Scenarios with Flexible Rotations and Fertilizer Management

Rotation	Un-restricted N Loss	10 % reduction	After Plan	20 % reduction	30 % reduction	40 % reduction	50% reduction	60% reduction
Corn, Wheat, Clover			52			26	26	26
Corn, Barley, Soybean	264	251	71	166	92	92	92	35
Corn, Barley, Alfalfa		13	141	98	172	145	96	67
Idle Cropland							50	135
Grazed Pasture	50	50	50	50	50	39	28	20
Idle Pasture						11	22	30
Total	314	314	314	314	314	314	314	314

While keeping all land in the corn, barley, soybean rotation increases farm returns above those estimated after the implementation of nutrient management, baseline nitrogen, phosphorus, and erosion losses are also higher (see Table 5.5). However, nitrogen losses are still lower than those occurring before nutrient management (see Table 5.2). When nitrogen losses are unrestricted, net economic return is $100,098 while total nitrogen loss is 17,313 pounds. Since no land is planted in alfalfa, which does not receive any nitrogen application, the change in crop rotations also results in higher total plant available nitrogen application for the farm when compared to current practices.

Table 5.5: Summary Statistics for Scenarios with Flexible Rotations and Fertilizer Management

Alternative (N loss restriction)	Net Economic Return ($)	Dairy Cows	Erosion (tons)	Total N Loss (lb.)	Total P Loss (lb.)	Manure N App.[a] (lb.)	Commercial N App. (lb.)	Total N App.[a] (lb.)
Unrestricted	100098	160	2389	17313	4054	13828	21103	34930
10 % reduction	99096	160	2499	15582	4311	13823	20104	33927
After Plan	89612	160	1981	14468	3482	13777	12677	26453
20 % reduction	97407	160	2132	13851	3817	13792	15323	29115
30 % reduction	93800	160	1967	12119	4000	13817	11446	25263
40 % reduction	82938	125	1567	10388	3493	10824	11069	21892
50 % reduction	65070	89	971	8657	2498	7691	10099	17791
60 % reduction	39204	64	472	6925	1437	5491	3668	9159

[a] Plant available application.

Nitrogen Loss Restrictions

Results from the scenario in which crop rotations are unconstrained and nitrogen loss is not restricted are used as a base of comparison for all other scenarios. As the restriction on nitrogen loss is tightened, both crop rotation selection and fertilizer application practices change (see Tables 5.4 and I.4). Initially, manure and commercial fertilizer application rates are varied across soils in both cropland and pasture while the majority of cropland is kept in the corn, barley, soybean rotation.

Manure applications to cropland are first restricted to the Frederick soils as nitrogen loss is restricted (see Figure 5.1). When manure loss is restricted to a 10 percent reduction, all manure is applied to the Frederick soil. No manure is applied to Nixa soil. This soil is very poor quality and has extremely high nitrogen losses compared to other soils (see Table F.2). The Nixa soil is kept in the corn, barley, soybean rotation but nitrogen is applied in split applications at a rate of 30 pounds per application based on nitrogen stress of the crop (EPIC's autofertilization option as described in chapter 4). Frederick soil with a 10.5 percent slope (AFTCBSFC) is either moved into the corn, barley, alfalfa rotation (AFTCBAFC) or has manure application reduced to 3000 gallons per acre (CBS3FC). While the reduction in manure application reduces nitrogen loss by 6.6 pounds per acre, the switch to corn, barley, alfalfa rotation results in a reduction of 27 pounds per acre (see Tables F.2 and F.4).

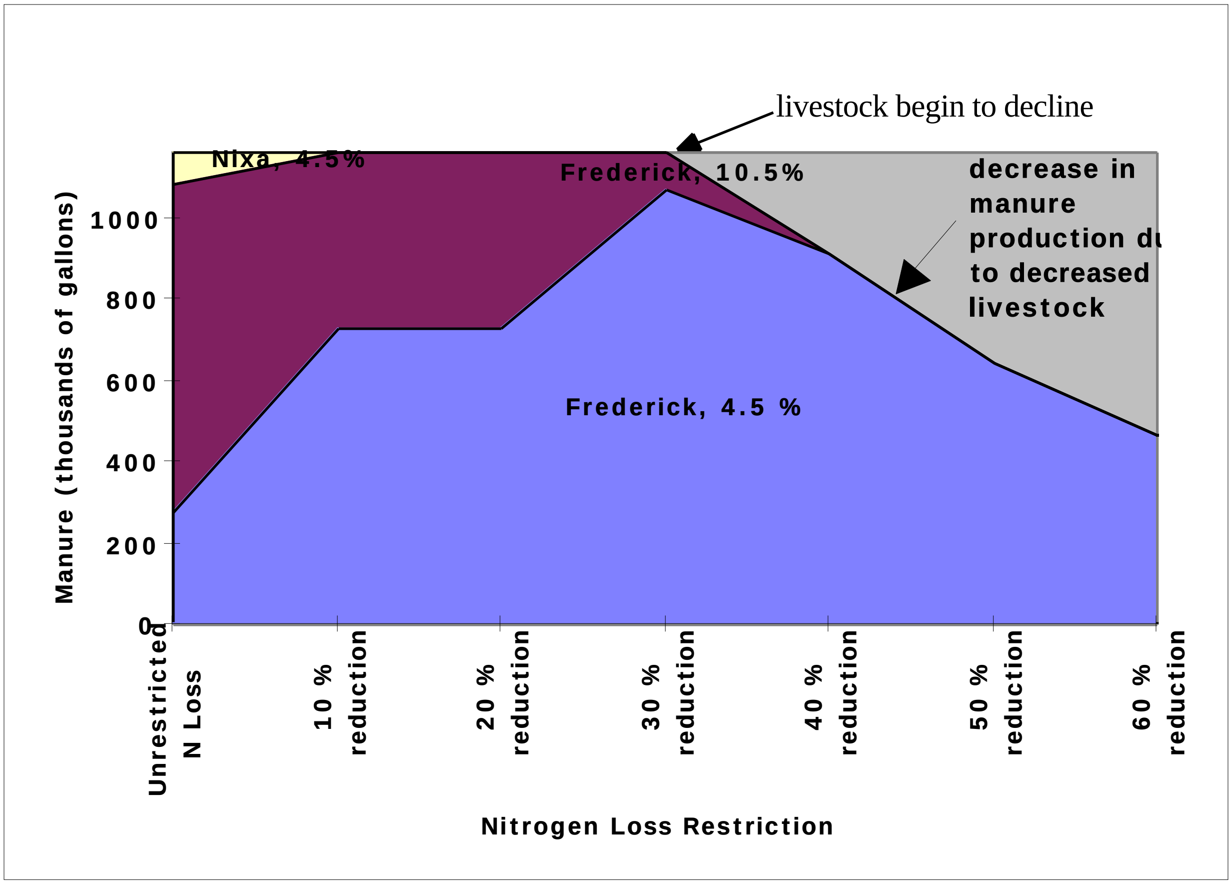


Figure 5.1: Manure Appliction by Soil and Slope

Manure is concentrated most heavily on the Frederick soil with a 4.5 percent slope. This soil has the lowest losses associated with high manure application rates and therefore receives an application of 6,000 to 12,000 gallons per acre. The increase in nitrogen losses from this soil associated with increased manure applications are more than offset by reductions in losses from the other two soils.[7] The increase in manure application from 3,000 gallons per acre (CBS3FB) to 6,000 gallons per acre (AFTCBSFB) increases nitrogen losses by 2.4 pounds per acre while the increase to 12,000 gallons of manure (CBS12FB) results in an increase in nitrogen loss by 7.5 pounds per acre (see Table F.2).

As the nitrogen loss restriction is tightened further, manure is concentrated more heavily on the Frederick soil with 4.5 percent slope while Frederick soil with a 10.5 percent slope is switched to EPIC's autofertilization option (see Table J.1). Nixa soil also receives no manure applications.

In addition to changes in manure application rates, crop rotations are altered as nitrogen loss is restricted. For example, land is switched to a corn, barley, alfalfa rotation as the restriction on nitrogen loss is increased (see Table 5.4 and Figure 5.2). This rotation has lower estimated nitrogen losses than the corn, barley, soybean rotation regardless of management practice.

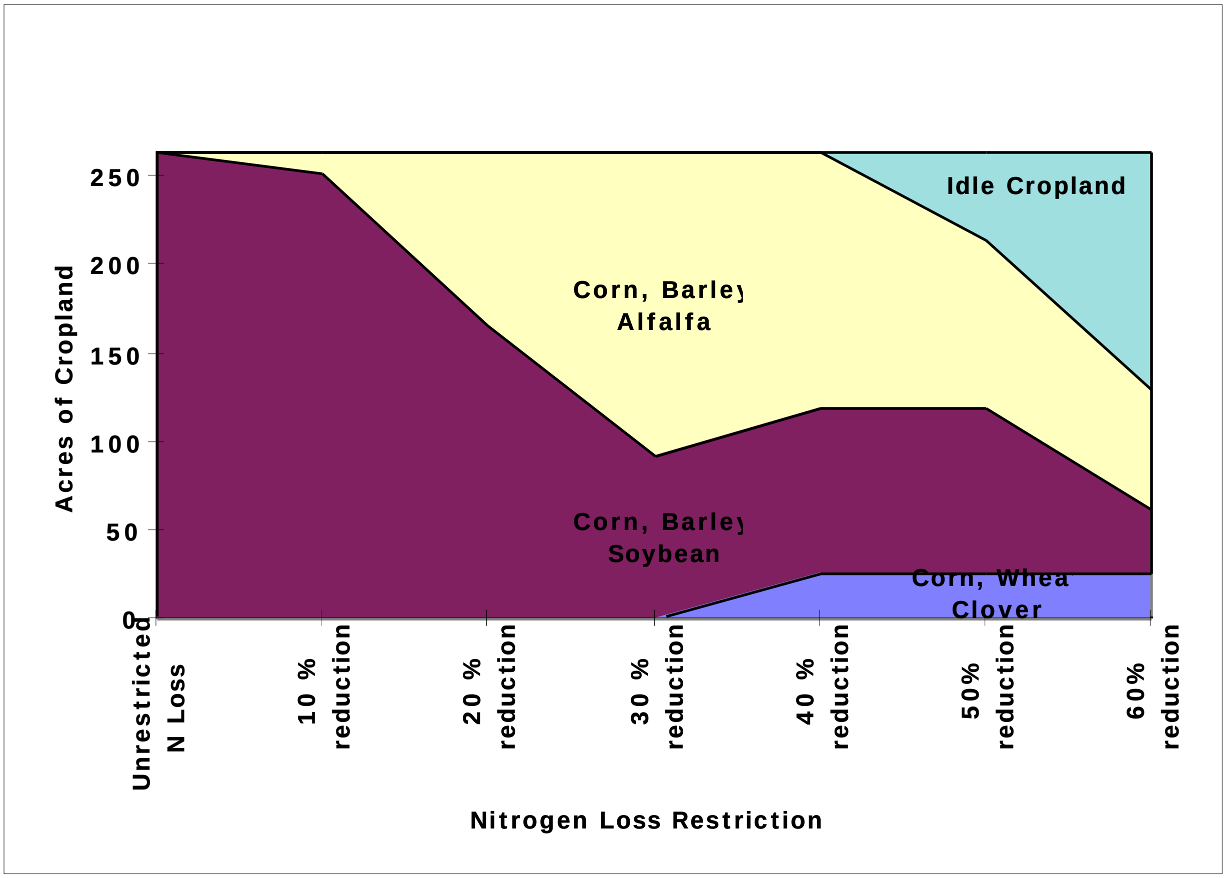


Figure 5.2: Crop Rotation Selection

[7] See Appendix F for nutrient losses across soils as manure application rates vary.

Nitrogen losses after nutrient management planning on Farm 2 are between the 10 and 20 percent reductions in nitrogen losses when rotation and fertilizer management are unrestricted (see Table 5.5). After nutrient management planning, manure is applied to all corn and small grains at a rate of 6,000 gallons per acre. In comparison to a 10 percent reduction, less land is in the corn, barley, soybean rotation after nutrient management planning and more alfalfa is grown (see Table 5.4). Also, 52 acres are in the corn, wheat, clover cover rotation after nutrient management planning. With the 10 percent reduction in nitrogen loss, no land is in the corn, wheat, clover rotation. As nitrogen loss is reduced by 20 percent, more land is planted in alfalfa than with a 10 percent reduction. Farm level nitrogen losses could be reduced up to 30 percent below baseline losses (with flexible crop rotations and management) with higher farm returns than those estimated after nutrient management.

When nitrogen loss is restricted to a 30 percent reduction below baseline nitrogen losses, 171.6 acres of cropland is in the corn, barley, alfalfa rotation, while only 92.4 acres remain in the corn, barley, soybean rotation. This results in approximately 86 acres of cropland in alfalfa each year. Both the Nixa soil and the Frederick soil with a 10.5 percent slope are in the corn, barley, alfalfa rotation. The Frederick soil with a 4.5 percent slope remains in the corn, barley, soybean rotation. The change in crop production does not increase the amount of feed purchases needed to meet the requirements of livestock. Instead, it reduces the amount of excess forage production available for sale (see Tables I.3 through I.9).

As the nitrogen loss is reduced more than 30 percent, livestock numbers are reduced and cropland is switched to the corn, wheat, clover rotation. Nitrogen losses can be reduced by up to 40 percent while keeping all cropland in production. However, after that point, cropland is removed from production and planted with a cover crop while the amount of grazed pasture is reduced (see Appendix I). Ultimately, nitrogen loss can be reduced up to 60 percent below baseline losses. This is a 52 percent reduction below losses estimated after the adoption of the nutrient management plan. It is not possible to reduce nitrogen loss 70 percent below baseline losses even if all land is taken out of production.

Reductions in nitrogen loss as the nitrogen loss restriction is tightened are largely due to a reduction in organic nitrogen losses associated with changes in manure application practices discussed above(see Table 5.6). However, even after the reduction in nitrogen losses, loss of organic nitrogen with sediment remains the largest loss pathway accounting for more than 50 percent of total EPIC estimated nitrogen losses (see Figure 5.3). Any further reductions in nitrogen losses need to deal with this loss pathway in particular. It appears that this farm would be a prime candidate for the use of practices such as terraces to reduce losses with runoff. However, any structure that reduces losses with sediment is very likely to increase losses through percolation.

As nitrogen losses are reduced, phosphorus losses fluctuate (see Table 5.6). This fluctuation seems to be a result of the variation in manure application rates as the nitrogen loss restriction is tightened. When manure applications are reduced, commercial phosphorus is substituted as explained in Chapter 4. EPIC estimates higher losses from commercial phosphorus than from manure phosphorus. Also, when manure application are increased from 6,000 gallons to 12,000 gallons, phosphorus losses increase significantly. This can be seen by examining the data for the corn, barley, soybean alternatives found in Table F.2. For example, on the Frederick soil with a 4.5% slope, phosphorus losses are 5.8 pounds per acre when 12,000 gallons of manure are applied to corn and barley (CBS12FB). When only 6,000 gallons of manure are applied (AFTCBSFB), phosphorus losses are only 4 pounds per acre. However, when only commercial phosphorus is applied at a rate equal to plant available phosphorus from manure

(NOMANCBSFB), phosphorus losses are 5.4 pounds per acre. Once land is pulled out of production to meet nitrogen loss restrictions (below 40% reduction), farm level phosphorus losses decline consistently.

Table 5.6: Nutrient Losses (lb.) with Flexible Rotations and Fertilizer Management

Loss Pathway	Unrestricted N Loss	10 % reduction	20 % reduction	30 % reduction	40 % reduction	50% reduction	60 % reduction
Nitrate Loss w/ Runoff	1136	1083	1074	934	878	743	579
Organic N w/ Sediment	12546	11512	9850	8558	7444	5726	3815
Mineral N w/ Subsurface Flow	1332	1248	1205	1000	897	943	1092
Mineral N with Percolate	2299	1739	1722	1627	1169	1244	1440
Total N Loss	17313	15582	13851	12119	10388	8657	6925
Soluble P in Runoff	5	16	24	29	26	21	12
P Loss with Sediment	4048	4295	3792	3971	3467	2477	1425
Total P Loss	4054	4311	3816	4000	3493	2498	1437

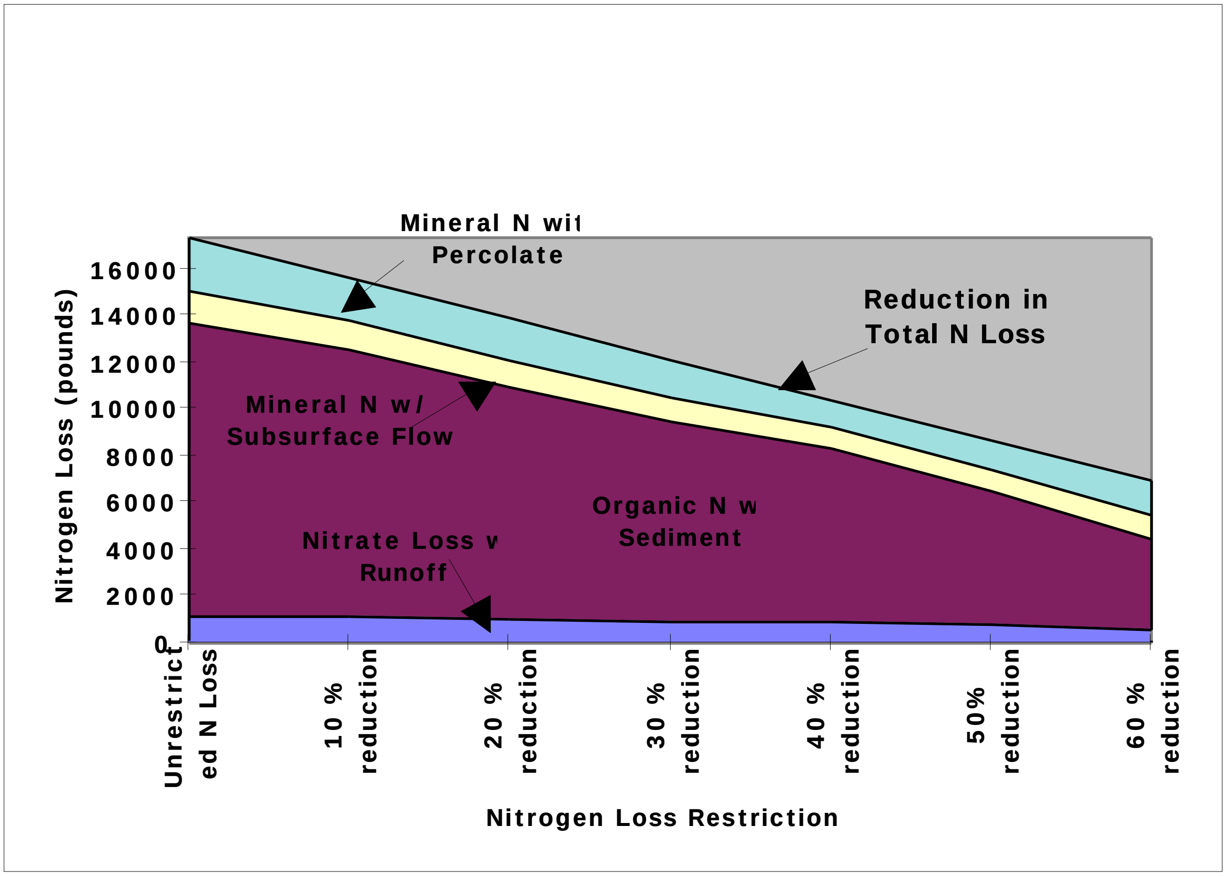


Figure 5.3: Nitrogen Loss Pathways with Flexible Rotations and Fertilizer Management

When crop rotation selection is unconstrained, it is possible to achieve the current level of nitrogen loss reduction (after adoption of the nutrient management plan) while increasing farm income (see Table 5.7 and Figure 5.4). Farm level nitrogen loss could be reduced up to 16 percent below those losses estimated after the nutrient management plan without reducing farm income. While achieving initial reductions in nitrogen losses may have little or no impact on farm returns, the cost per pound of nitrogen loss reduction increases as the restriction on losses increases (see Table 5.7 and Figure 5.5). The reduction in nitrogen loss by 60 percent results in a significant reduction in farm income.

Table 5.7: Cost Per Pound of Nitrogen Loss Reduction

Alternative (N loss Restriction)	Net Economic Return ($)	N Loss (lb.)	Average Cost Per Pound Reduction [a] ($)	Marginal Cost Per Pound Reduction [a] ($)
Unrestricted N Loss	100098	17313		
10 % reduction	99096	15582	0.57	0.57
20 % reduction	97407	13851	0.77	0.98
30 % reduction	93800	12119	1.21	2.08
40 % reduction	82938	10388	2.47	6.27
50 % reduction	65070	8657	4.05	10.32
60 % reduction	39204	6925	5.86	14.94

[a] Cost is in terms of reduced net economic return.

In achieving reductions in nitrogen loss, EPIC's autofertilization option is used on soils more susceptible to nitrogen losses while manure applications are increased on soils less susceptible to nitrogen losses. While the autofertilization option results in the least impact on farm net economic returns, it is not a necessary practice to achieve reductions in losses. As noted in the explanation of management alternatives in Chapter 4, in the use of the autofertilization option, EPIC may apply fertilizer after the time in which it could be applied to a crop with field spreading equipment. If the autofertilization option is not included in the model, it is still possible to achieve the same reduction in nitrogen loss through changes in manure application rates and crop rotations. Also, livestock numbers are reduced earlier. When the autofertilization option is not used, the cost of achieving nitrogen loss reductions is higher. Nitrogen losses can be reduced up to 60 percent but farm income is reduced to $24,618. However, it is still possible to achieve more than a 16 percent reduction in farm level nitrogen loss below those losses estimated after the nutrient management plan without reducing farm income.

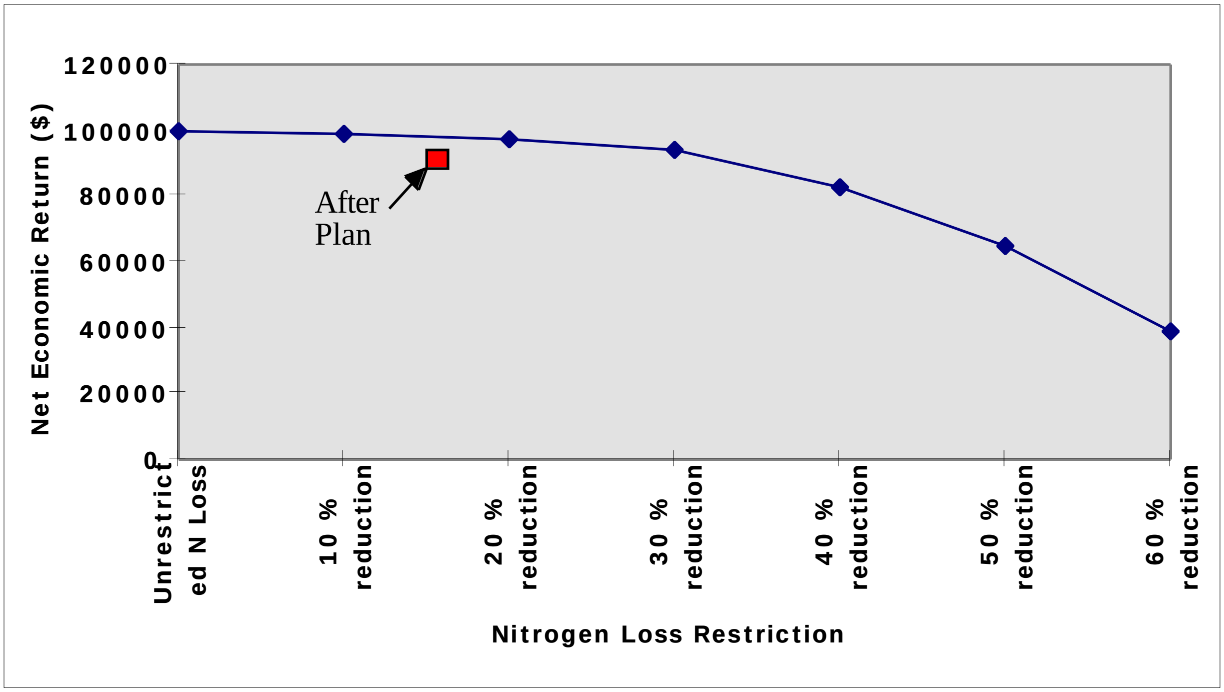


Figure 5.4: Farm Return with Nitrogen Loss Restrictions

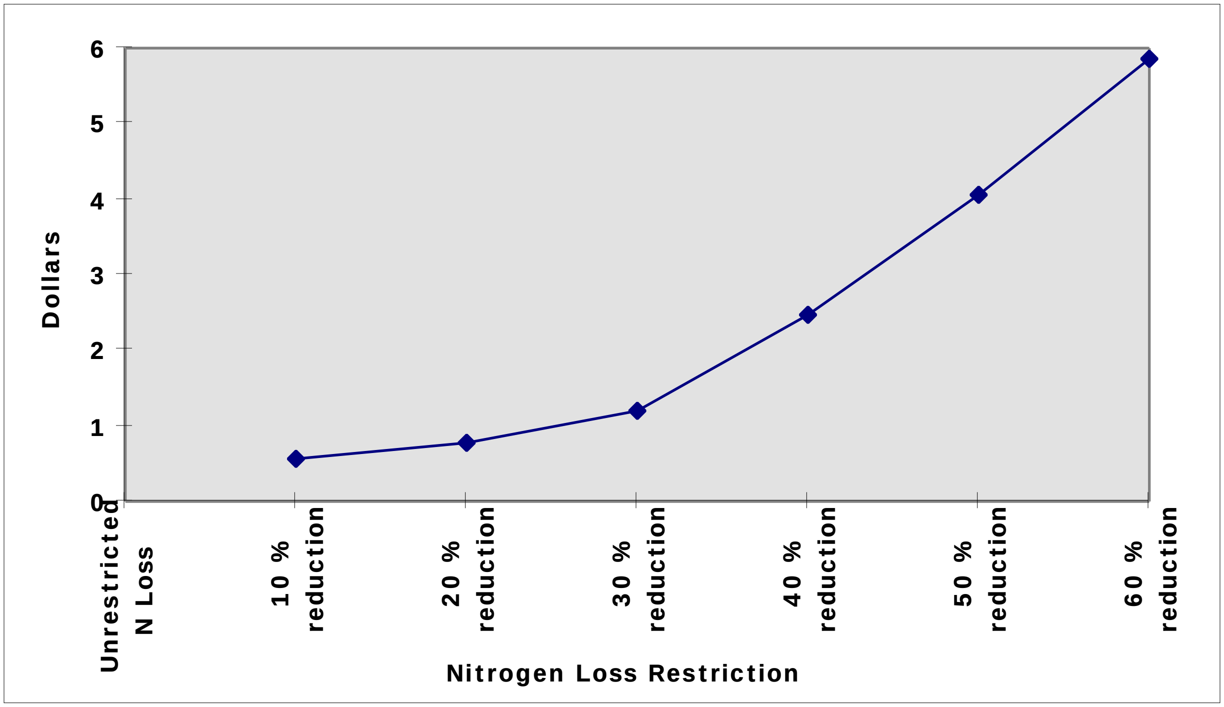


Figure 5.5: Average Cost Per Pound of Nitrogen Loss Reduction

Nitrogen Loss Scenario with Restricted Rotations

While significant reductions in nitrogen losses can be achieved through changes in fertilizer management and crop rotations, it is unclear how much of the possible reductions are attributed to changes in fertilizer management practices rather than crop rotation changes. Therefore, the model is restricted to current crop rotations while any fertilizer management practices may be used (see Table 5.8). Once again, all manure must be applied to cropland and pasture. For this and all other scenarios, baseline results are those estimated when both crop rotations and fertilizer management practices are flexible and nitrogen loss is unconstrained.

Table 5.8: Acreage of Crop Rotations

Crop Rotation	Acres
Corn, Wheat, Clover Cover	52
Corn, Barley, Soybean	71
Corn, Barley, (Soybean) Alfalfa	141
Continuously Grazed Pasture	50
Total	314

When crop rotations are restricted, unconstrained nitrogen loss is 16 percent below baseline nitrogen losses while farm return is 10 percent lower (see Table 5.9). While holding crop rotations and livestock numbers constant, it possible to achieve a 26 percent reduction below baseline estimated nitrogen losses. This reduction is 41 percent below losses estimated before the adoption of the nutrient management plan.

Table 5.9: Summary Statistics with Restricted Crop Rotations

Alternative (N loss restriction)	Net Economic Return ($)	Dairy Cows	Erosion (tons)	Total N Loss (lb.)	Total P Loss (lb.)	Manure N App. (lb.)	Commercial N App. (lb.)	Total N App. (lb.)
Baseline [a]	100098	160	2389	17313	4054	13828	21103	34930
Unrestricted N Loss w/ Restricted Rotations [b]	89639	160	1965	14466	3530	13781	12771	26552
20 % reduction	89400	160	2044	13851	3625	13781	12138	25919
26 % reduction	86419	160	2149	12800	4229	13777	11495	25272

[a] Baseline is flexible rotation and fertilizer management with no restriction on nitrogen loss.

[b] When nitrogen loss is unconstrained, farm returns and nutrient losses are almost identical to those estimated after the adoption of the nutrient management plan. However, differences in crop yields, as estimated by EPIC, result in variations in application rates of manure (see Appendix J). These changes in fertilization application practices result in a slight increase in farm returns by $27 and phosphorus losses by 48 pounds compared to after the nutrient management plan (see Table 5.2).

As when crop rotations are unrestricted, reductions in nitrogen loss are achieved through an alteration of manure application rates. Higher manure applications (cropland) are made to the Frederick soil while manure applications to the Nixa soil are reduced or eliminated (see Appendix J). In addition to routing manure to soils less susceptible to nitrogen losses, high manure applications are also made to rotations subject to lower losses. For example, as the restriction on nitrogen losses is tightened to 26 percent below baseline losses, manure is predominantly applied to land in the corn, wheat, clover rotation (see Appendix J). Most land in the corn, barley, soybean rotation receives only commercial fertilizer. In pasture, manure is applied at high rates to the 4.5 percent and 10.5 percent slopes while no manure is applied to steeper slopes. These soils receive only commercial fertilizer.

The alternative routing of manure within the farm results in a reduction of nitrogen losses from all loss pathways (see Table 5.10). However, the most significant decrease is organic nitrogen loss with sediment, which is the largest source of nitrogen losses from Farm 2. With the change in application rates of manure, the increases in organic nitrogen losses on the soils receiving higher manure applications are more than offset by decreases in losses from soils no longer receiving manure. For example, the alternative routing of manure allows soils more susceptible to nitrogen losses, such as the Nixa, to receive only commercial fertilizer which is applied in split applications so as to coincide better with plant needs and reduce losses.

Table 5.10: Nutrient Losses (lb.) with Restricted Crop Rotations

Loss Pathway	Unrestricted N Loss	20 % reduction [a]	26 % reduction [a]
Nitrate Loss w/ Runoff	1078	1058	877
Organic N w/ Sediment	10091	9708	9387
Mineral N w/ Subsurface Flow	1257	1201	1008
Mineral N with Percolate	2038	1884	1528
Total N Loss	14466	13851	12800
Soluble P in Runoff	16	17	22
P Loss with Sediment	3514	3608	4206
Total P Loss	3530	3625	4228

[a] Reduction in comparison to baseline losses with flexible rotation and fertilizer management and no restriction on nitrogen loss.

As when crop rotations are flexible, reductions in nitrogen loss become more costly as the nitrogen loss restriction is tightened (see Table 5.11).

Table 5.11: Cost Per Pound of Nitrogen Loss Reduction with Restricted Rotations

Alternative (N loss Restriction)	Net Economic Return ($)	N Loss (lb.)	Average Cost Per Pound Reduction [a] ($)	Marginal Cost Per Pound Reduction [a] ($)
Unrestricted N Loss	89639	14466		
20 % reduction [b]	89400	13851	0.39	0.39
26 % reduction [b]	86419	12800	1.93	2.84

[a] Cost is in terms of reduced net economic return.
[b] Reduction in comparison to baseline with flexible rotation and fertilizer management and no restriction on nitrogen loss.

The results of this model suggest that crop rotation selection may play an important a role in achieving nitrogen loss reductions with minimal impact on farm returns. When model activities are restricted to crop rotations and livestock numbers produced after the adoption of the nutrient management plan, it is possible to achieve a 26 percent reduction in baseline nitrogen losses. However, farm economic returns are reduced approximately 14 percent. When crop rotations are flexible, it is possible to reduce nitrogen losses 30 percent without reducing livestock numbers. Farm returns are reduced only 6 percent. While it is possible to achieve nitrogen loss reductions with changes in only fertilizer management practices, flexibility in crop rotations allows for nitrogen loss reductions to be achieved with higher farm net economic returns.

Sensitivity Analysis

The scenario in which crop rotations and fertilizer management practices are flexible and no restriction is placed on nitrogen loss is used as a baseline of comparison for sensitivity analysis. As in all other scenarios examined, all manure must be applied to cropland and pasture included in the model. Nitrogen loss is varied parametrically to determine how low it is possible to reduce nitrogen losses as changes in the model are made. When livestock numbers are increased, it is assumed that facilities present on the farm are sufficient to handle the increase.

Increased Livestock

When livestock numbers are increased by 10 percent, it is possible to reduce nitrogen losses 40 percent below baseline nitrogen losses (see Table 5.12). When livestock numbers are increased by 20 percent, it is possible to reduce nitrogen losses more than 20 percent below baseline losses. However, it is not possible to maintain nitrogen losses at a 40 percent reduction below baseline losses with a 20 percent increase in livestock.

The cost (in terms of foregone net economic returns) of achieving or maintaining the same level of nitrogen loss reduction below baseline losses is much higher when livestock numbers are increased (see Table 5.12 and Figure 5.6). The decrease in returns is most pronounced when livestock numbers are increased by 10 percent (176 dairy cows) and nitrogen loss is not permitted to exceed a forty percent reduction in baseline losses. In this case, farm returns are decreased by $44,517. Net returns with increased livestock would be further reduced if the cost of facility expansion were considered.

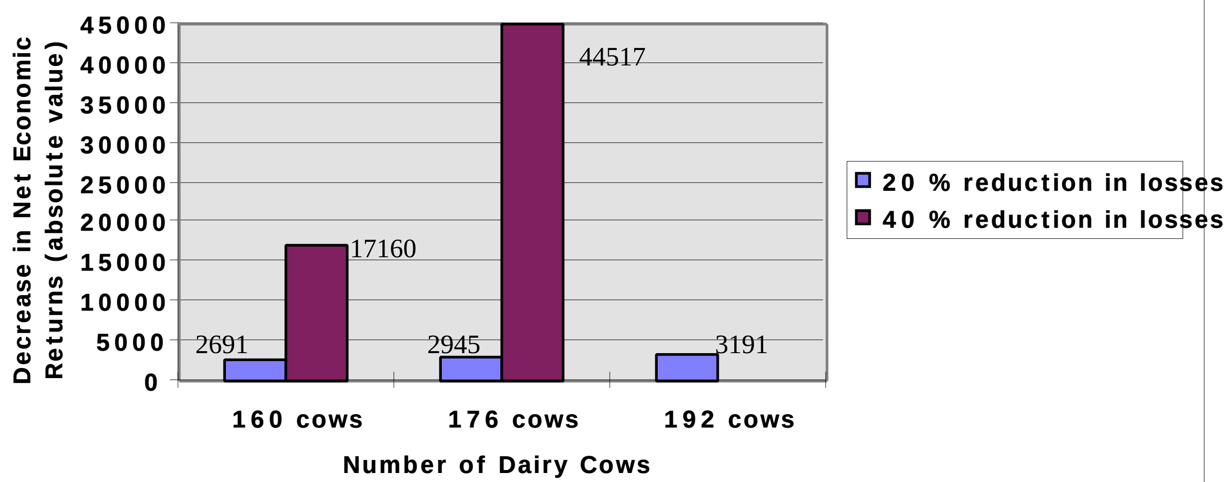
Table 5.12: Net Returns and Nitrogen Losses with Increased Livestock

N Loss	160 Dairy Cows		176 Dairy Cows		192 Dairy Cows	
Restriction	Returns ($)	N Loss (lb.)	Returns ($)	N Loss (lb.)	Returns ($)	N Loss (lb.)
Unrestricted	100098	17313 [a]	103664	17611	107222	17789
20 % reduction [b]	97407	13851	100719	13851	104030	13851
40 % reduction [b]	82938	10388	58747	10388	N/A	N/A

[a] Baseline nitrogen losses.

[b] Reduction in comparison to baseline losses.

Figure 5.6: Change in Farm Returns with Nitrogen Loss Restrictions



In order to reduce nitrogen losses while increasing manure production, more land is removed from production than when only 160 dairy cows are produced on the farm (see Tables 5.13 and 5.4). The removal of land from production in addition to the increase in livestock numbers results in a reduction or elimination of the sale of excess forage production. Also, all feed purchases are increased. Manure is applied to Frederick soil with a 4.5 percent slope at a rate of 9,000 or 12,000 gallons per acre annually while Nixa soil receives only commercial fertilizer (see Table K.1).

Table 5.13: Crop Rotation Selection with Increased Livestock

Rotation	Baseline	10 % increase in livestock [a]	20 % increase in livestock [b]
Corn, Wheat, Clover		111	26
Corn, Barley, Soybean	264	26	92
Corn, Barley, Alfalfa		31	119
Idle Cropland		96	26
Grazed Pasture	50	50	50
Idle Pasture			
Total	314	314	314

[a] Forty percent reduction in baseline nitrogen losses.

[b] Thirty percent reduction in baseline nitrogen losses.

Change in milk price

When milk price is altered, it is possible to achieve the same reduction in nitrogen losses as in the baseline. When milk price is increased by 25 percent, farm economic returns are consistently higher at all nitrogen loss levels. However, crop rotation selection is identical to the baseline. When milk price is lowered by 25 percent, no livestock are produced. Therefore, unrestricted nitrogen losses are lower than baseline losses. Farm income is also much lower when no livestock is produced.

Summary

Results of the linear programming model suggest that additional reductions in nitrogen losses below those estimated for practices used after the nutrient management plan can be achieved through the alternative routing of manure applications within a farm based on soils and crop rotations. The over application of nitrogen on selected fields, due to high manure applications (12,000 gallons per acre), may allow for further reduction of nitrogen losses from the farm as a whole. While the over application may increase losses on individual fields, these increases may be more than offset by decreases in nitrogen losses from fields in which manure application is reduced or eliminated.

Initial reductions in nitrogen losses have little or no impact on farm net economic return. Whether crop rotations are restricted to current rotations (after nutrient management plan) or are unrestricted, it is possible to reduce nitrogen losses below those estimated after nutrient management while increasing farm return. Holding crop rotations constant while allowing for alteration of fertilizer application rates, nitrogen losses can be reduced 12 percent below after plan losses while decreasing farm economic return less than $200 (3.5 percent). At this level, nitrogen losses are 41 percent below losses estimated before the implementation of the nutrient management plan. When crop rotation is unrestricted, nitrogen losses can be reduced more than 16 percent below losses after the nutrient management plan without decreasing net returns below those estimated with current practices.

While holding crop rotations constant, it is not possible to reduce EPIC estimated nitrogen losses more than 12 percent below those losses estimated after the nutrient management plan. However, when crop rotations are also flexible, it is possible to reduce nitrogen losses up to 52 percent below losses estimated after the plan. While initial reductions in nitrogen loss have little impact on farm income, farm income decreases more sharply as the nitrogen loss restriction is tightened.
A 52 percent reduction in nitrogen loss also reduces farm income by 56 percent. The results of this model suggest that crop rotation selection may play as important a role in achieving nitrogen loss reductions as fertilizer management practices. Flexibility in crop rotations allows for nitrogen loss reductions to be achieved with higher farm net returns while also allowing for greater reductions to be achieved in comparison to rigid crop rotations.

While nitrogen loss can be reduced through the alteration of fertilizer management practices and crop rotations, at some point it becomes necessary to reduce livestock numbers to achieve further reductions. At some point it is impossible to achieve further reductions in nitrogen loss without reducing the amount of animal wastes to be disposed of on the farm. Also, it will eventually be necessary to remove soils more susceptible to high losses from production.

In all scenarios examined, over 50 percent of total farm nitrogen losses are lost as organic nitrogen with soil. Any further reduction in nitrogen loss would need to address this loss pathway. This farm appears to be a prime candidate for the use of structural practices, such as terraces or strip cropping, in the reduction on nutrient losses. However, any practice used to reduce erosion and therefore surface losses of nutrients is likely to increase percolation losses of nitrogen.

Chapter 6: Summary and Conclusions

Study Summary

This study focuses on the evaluation of management practices designed to reduce the loss of nitrogen from livestock farms in Virginia, variation of results across soils, and opportunities for further reducing nitrogen losses. In Virginia, one of the major emphases in the struggle to control pollution resulting from agricultural activities is the adoption of conservation practices in the form of a nutrient management plan indicating how nitrogen, phosphorus, and potassium will be managed annually so as to meet crop needs while considering the protection of water quality. Nutrient management plans can be particularly important on livestock farms where the application of animal wastes in addition to commercial fertilizers increases the potential of a farm to contribute to pollution problems.

While nutrient management planning is currently one of the more important nonpoint source programs in Virginia, evaluation of the on-farm environmental and economic impacts is lacking. It is unknown what level of reduction in potential nitrogen losses to surface and groundwater results from compliance with the plans. As a result, the environmental and economic tradeoffs implied by nutrient management plans are uncertain.

Although it is well known that farm characteristics are associated with the outcome of alternative management practices, knowledge about the linkages among farm practices, soil quality, and water quality is piecemeal. While great progress has been made, more specific information is needed on the effects of farm practices and crop management decisions on water quality (Bosch et al.). More information is also needed relating soils and cropping systems to regional water quality problems (Galeta et al.). It is unknown by policy implementors whether alternative management practices could achieve greater reductions in nutrient losses than those achieved currently or if reductions could be achieved at a lower cost.

This study has three specific objectives:

1. To analyze the effects of nutrient management practices on farm net returns and nitrogen loss for four livestock farms in Virginia.

2. To examine the effects of soil type and slope on the costs of achieving nitrogen loss reductions.

3. To examine methods for improving nutrient management planning in order to either achieve greater nitrogen loss reductions than those currently achieved without decreasing farm profits or achieve current reductions at a lower cost.

Nutrient Management Planning

The effects of nutrient management practices on farm profit and farm-level nitrogen loss across sample livestock farms in Virginia are analyzed for four case farms: 1) Southwestern Virginia Dairy, 2) Shenandoah Valley Dairy, 3) Southeastern Virginia Crop and Swine, and 4) Piedmont Poultry. These farms were chosen through consultation with nutrient management specialists to represent a cross section of Virginia livestock producers. This analysis includes examination of the effect of identified livestock farm physical characteristics on the results of nutrient management practices; specifically the impact of soil type and slope on the cost-effectiveness of nutrient management practices.

The Erosion Productivity Impact Calculator, EPIC, is used to estimate the changes in crop yields and nutrient losses before and after the implementation of a nutrient management plan while partial budget analyses are used to examine impacts of the plans on farm net income. EPIC estimates nutrient losses at the edge of the field and the edge of the root zone. Therefore, estimated losses represent only *potential*, not actual, loadings to water bodies.

As a result of the implementation of the nutrient management plans, estimated nitrogen losses are reduced by 23 to 45 percent while farm income increased from $365 to $7,249. The highest reductions in nitrogen loss are seen on the Shenandoah Valley Dairy and the Southeastern Virginia Crop and Swine farm. These two farms concentrated high volumes of manure on a small amount of land near the animal production facilities prior to the adoption of the plan. These practices were followed due to a lack of storage facilities for manure. With the implementation of the plan, manure storage facilities were installed which allowed for manure to be stored until most beneficial to crops and to be applied to larger areas of cropland. The smallest reduction in farm level nitrogen losses is on the Piedmont Poultry. This farms consists entirely of well maintained pasture with modest slopes. This farm also had the smallest per acre losses prior to the adoption of the plan. While the Piedmont poultry had the smallest reduction in nitrogen loss, this farm also had the highest increase in income. This increase is due to the sale of excess poultry litter resulting from the reduction in application rate to pasture. On all other farms, the increase in income is primarily due to a reduction in the use of commercial fertilizer with the implementation of the nutrient management plan.

While the reduction in nitrogen loss varies across farms, the variation in nitrogen loss reductions within farms is greater. For example, on the Shenandoah Valley Dairy, nitrogen loss reductions vary from 5 to 50 percent depending on soil and crop rotation. This farm has numerous crop rotations and three soils with multiple slopes. This farm contains one very good quality soil, Frederick, and one poor quality soil, Nixa. The Nixa soil is very cherty soil with high percolation losses. Total nitrogen losses on the Nixa soil are 1.7 to 4.7 times higher than losses from the Frederick soil regardless of rotation. However, adoption of the nutrient management planning also results in much higher reductions on the Nixa soil. For example, in the corn, wheat, clover cover rotation, nitrogen losses on the Frederick soil with a 10.5 percent slope are reduced by 21 percent (10 pounds) while losses on the Nixa soil with a 10.5 percent slope are reduced by 48 percent (60 pounds).

While soil type impacts nutrient losses, the slope also is important. Generally, as the slope increases, the percentage reduction in nitrogen losses decreases while the absolute reduction in pounds increases. This can be seen by examining the results on Farm 1, the Southwestern Virginia Dairy (see Table 3.2). On the Frederick soil with a 4.5 percent slope, a 39 percent reduction in nitrogen loss is achieved while a 29 percent reduction in nitrogen loss is achieved on the 10.5 percent slope. This trend is also observed on the Groseclose soil where a 38 percent reduction is seen on the 4.5 percent slope while a 28 percent reduction is seen on the 10.5 percent slope and a 21 percent reduction is seen on the 16.5 percent slope.

Opportunities for Improvement in Nutrient Management Planning

Methods for improving nutrient management planning at the farm level in order to achieve greater nitrogen loss reductions are evaluated using a linear programming model developed for Farm 2, the Shenandoah Valley Dairy. The overall purpose of the model is to examine methods for improving nutrient management planning at the farm level (rather than the field level) in order to achieve greater nitrogen loss reductions without decreasing farm profits. The variety of rotations, soils, and slopes present on the farm allows for examination of the possibility to reduce nitrogen losses below current levels through targeting alternative management practices within the farm, particularly the alternative routing of manure and commercial fertilizers.

The linear programming model maximizes returns over variable costs subject to constraints on the amount of specific soils present on the farm, livestock numbers, feed ration requirements, manure use, pasture restrictions, and nitrogen loss. Thirteen management alternatives for cropland and five alternatives for pasture are included in the model. The management alternatives are designed to allow the model to modify manure and commercial application practices across soils and rotations to meet nitrogen loss restrictions. The model may also remove land from production. The linear programming model for the farm is able to target management practices to individual soils, slopes, and rotations to meet nitrogen loss restrictions.

As in the case farm analysis, crop yields and potential nutrient losses are estimated through the use of the EPIC simulation model. Nutrient losses are estimate at the edge of the field and the edge of the root zone and therefore represent potential loadings, not actual loadings, to water bodies.

Several alternatives were examined with the linear programming model. First, the model is restricted to management practices followed prior to the adoption of the nutrient management plan. Second, the model is restricted to rotations and fertilizer management practices used after the implementation of the plan. Next, the nitrogen loss constraint is varied parametrically with and without flexible crop rotations. Finally, sensitivity analysis is conducted.

In general, the EPIC simulation model estimates higher losses from manure nitrogen than from corresponding applications of commercial nitrogen . Increasing the application rate of manure applied to a rotation increases nitrogen losses regardless of soil even with corresponding reduction in commercial fertilizer applications. However, the increase in nitrogen loss from Frederick soil with a 4.5 percent slope when manure application is increased is less than the decrease in losses from the Frederick soil with a 10.5 percent slope or Nixa soil with a corresponding decrease in manure application. The lowest nitrogen losses from all soils and crop rotations occur when commercial fertilizer (no manure) is applied based on nitrogen stress of the crop as determined by EPIC.

With the adoption of the nutrient management plan, farm level nitrogen losses are reduced by 34 percent while phosphorus losses are reduced by 40 percent and net economic return increases by $9,644. However, it is possible to achieve reductions in nitrogen loss below those estimated for practices used after nutrient management planning with little or no impact on farm net economic returns. When crop rotations are restricted to those used after the adoption of the nutrient management plan, it is possible to reduce nitrogen loss 12 percent below after plan losses while decreasing farm income only $200. This is a 41 percent reduction below losses estimated before the adoption of the nutrient management plan. When crop rotations are flexible, nitrogen losses can be reduced more than 16 percent below after plan losses without decreasing farm returns.

When crop rotations are flexible, it is possible to reduce nitrogen losses up to 52 percent below losses estimated after the implementation of the nutrient management plan. However, while initial reductions in nitrogen loss have little impact on farm income, the cost per pound of nitrogen loss reduction increases as the restriction on total losses is increased. While initial reductions cost $0.57 per pound, as nitrogen loss constraint is tightened reductions cost an average of up to $5.86 per pound. A 52 percent reduction in nitrogen loss reduces farm income by 56 percent.

The results of this model suggest that crop rotation selection may play an important a role in achieving nitrogen loss reductions with minimal impact on farm returns. When model activities are restricted to crop rotations and livestock numbers produced after the adoption of the nutrient management plan, it is possible to achieve a 26 percent reduction in baseline nitrogen losses. However, farm economic returns are reduced approximately 14 percent. When crop rotations are flexible, it is possible to reduce nitrogen losses 30 percent (while holding livestock numbers constant) with only a 6 percent reduction in farm returns. While it is possible to achieve nitrogen loss reductions with changes in only fertilizer management practices, flexibility in crop rotations allows for nitrogen loss reductions to be achieved with higher farm net economic returns.

As farm level nitrogen losses are reduced, total phosphorus losses fluctuate. This fluctuation seems to be a result of the variation in manure application rates as the nitrogen loss restriction is tightened. EPIC estimates higher losses from commercial phosphorus than from manure phosphorus. When manure applications are reduced on a soil, commercial fertilizer applications are increased to keep plant available applications consistent. Also, when manure application is increased on soils, phosphorus applications increase significantly. Unlike nitrogen losses, these increases in phosphorus loss on soils receiving higher manure applications are not necessarily offset by decreases in losses from soils receiving less manure.

In discussion of sensitivity analysis results, the scenario in which crop rotation and fertilizer management is flexible and nitrogen loss is unconstrained is used as a baseline of comparison.

When livestock numbers are increased by 10 percent, it is possible to reduce nitrogen losses 40 percent below baseline nitrogen losses. When livestock numbers are increased by 20 percent, it is possible to reduce nitrogen losses more than 20 percent below baseline losses. However, it is not possible to maintain nitrogen losses at a 40 percent reduction below baseline losses with a 20 percent increase in livestock.

The cost (in terms of foregone net economic returns) of achieving or maintaining the same level of nitrogen loss reduction below baseline losses is much higher when livestock numbers are increased. The decrease in returns is most pronounced when livestock numbers are increased by 10 percent (176 dairy cows) and nitrogen loss is not permitted to exceed a forty percent reduction in baseline losses. In this case, farm returns are decreased by $44,517. Net returns with increased livestock would be further reduced if the cost of facility expansion were considered.

When milk price is altered, it is possible to achieve the same reduction in nitrogen losses as in the baseline. When milk price is increased by 25 percent, farm economic returns are consistently higher at all nitrogen loss levels. However, crop rotation selection is identical to the baseline. When milk price is lowered by 25 percent, no livestock are produced. Therefore, unrestricted nitrogen losses are lower than baseline losses. Farm income is also much lower when no livestock is produced.

Implications

This study indicates that implementation of nutrient management plans on Virginia livestock farms results in significant reductions in nitrogen losses without adversely impacting farm income. On all the farms examined, nutrient management planning is a win-win situation in which nitrogen losses are reduced and farm income is increased. While reductions achieved on the four farms examined may not be enough to meet pollution reduction goals, the farms examined in this study are believed to be more concerned about manure nutrient utilization than the average producer. Therefore, it is likely that higher reductions in nitrogen loss would be achieved on other farms, particularly farms lacking manure storage facilities.

While the reductions achieved on the farms examined may not be enough to meet pollution reduction goals set by local, state, and federal governments, this study indicates that farm level (as opposed to field level) nutrient management planning may result in greater reductions in total nitrogen loss. Nutrient management planning currently limits both inorganic and organic fertilizer applications on all fields so as to not exceed crop requirements. On the farms examined, nutrient management plans result in an even distribution of manure across a large section of the farm while any nutrient deficiencies are made up with commercial fertilizer applications. However, after achieving initial reductions through 'blanket' reductions in manure and commercial fertilizer applications, variation in nutrient applications and losses across soils becomes important in achieving additional reductions.

This study shows that nitrogen losses could be further reduced by avoiding manure applications on soils with a high potential for losses. Manure applications should be concentrated on good quality soils with gentle slopes. Soils with steep slopes have extremely high nitrogen losses with sediment and runoff in comparison to gentler slopes. Extremely gravelly soils have high percolation losses compared to better quality soils. Poor quality soils have much lower nitrogen losses when commercial fertilizer is applied (no manure) in split applications based on crop nitrogen requirements. On all soils, nitrogen losses are higher from manure nitrogen than from commercial nitrogen. Results of this study suggest that it is beneficial, in terms of potential nitrogen loss, to apply manure at high rates on those soils and slopes less susceptible to nitrogen losses. Increased nutrient losses from such fields may be more than offset by reductions on soils more susceptible to nutrient losses.

The results of the linear programming model for Farm 2 show that it is important to consider the long term build-up of nutrients in the soil when determining the best method for applying animal wastes to cropland and pasture. This can be seen by comparing the case study analysis results for Farm 2, in which simulations were conducted for a three-year period, and the linear programming model results, in which simulations were conducted for a fourteen-year period. In the long term simulations, the build-up of organic nitrogen in the soil results in much higher organic nitrogen losses from soil receiving manure applications. As a result, higher reductions in total nitrogen loss are achieved on soils receiving manure applications prior to adoption of the nutrient management plan while smaller reductions are achieved on soils receiving manure after the adoption of the plan. While on this farm, the estimated reduction in nitrogen loss is almost identical over the long run as over the short term, the reduction is achieved in different areas. However, on other farms, this build-up in organic nitrogen over time may impact nitrogen loss reductions significantly resulting in higher reductions than those estimated for the four case farms over the short time period.

In addition to achieving higher nitrogen loss reductions over the long run, nitrogen losses would likely be further reduced through the use of alternative management practices not examined in this study. For example, on Farm 2, over 50 percent of all nitrogen losses occur in the form of organic nitrogen losses with sediment. This farm would be a prime candidate for the reduction of nitrogen losses through the use of structural practices such as buffer strips or terraces. However, the use of these practices may be more costly than those examined in this study.

Nutrient management planning can be an effective tool in reducing potential nitrogen loadings to surface and groundwater without imposing substantial costs on the producer. Linear programming results of Farm 2 show that nitrogen losses estimated before the adoption of the plan can be reduced over forty percent without decreasing after plan farm profits. In fact, even with an increase in livestock numbers, nutrient losses can be reduced through alternative routing of animal wastes. Losses on Farm 3 were also reduced over forty percent without negatively impacting farm income. These results suggest that nutrient management can be effective in achieving reductions in loadings to surface and groundwater and should continue to be a major focus in state water pollution control programs. However, in order to achieve nitrogen reduction goals, efforts should be made to ensure that the largest contributors to pollution problems are reached.

Study Limitations and Need for Further Research

The results of this study depend on assumptions made in the modeling process and the ability of EPIC to model management practices implemented on the case farms through nutrient management planning. However, EPIC is unfortunately unable to model some changes in management practices such as the use of soil tests and nitrate quick tests used to make a final determination of commercial fertilizer applications. Therefore, in the model, it was assumed that an average application is made to crops each year. Therefore, it is likely that in some years, excess nitrogen was applied (in EPIC simulations) while in other years applications were deficient of crop needs. Further research would be needed to determine if the use of nitrogen tests in determining fertilizer impacts results in further reductions in nitrogen loss than those estimated by EPIC.

While this study examines the ability to reduce nitrogen losses further through alternative fertilizer management practices, the impact of structural practices such as terraces or strip cropping on nutrient losses was not explored. However, linear programming results for Farm 2 suggest that the use of these practices may reduce losses even further. In all scenarios examine, over 50 percent of total farm nitrogen losses are lost as organic nitrogen with soil. Any further reductions would need to address this loss pathway.

Study results indicate that higher reductions in nitrogen loss may be achieved by targeting producers without manure storage facilities. However, only four farms were evaluated. The small number of case analysis conducted means that any conclusions drawn about impact of farm characteristics on nitrogen losses are hypotheses that need to be examined more closely in other studies.

Nutrient losses as discussed in this study are potential loadings, not actual loadings, to surface and groundwater. EPIC estimates for nitrogen and phosphorus losses are losses at the edge of the edge of the root zone. These losses may or may not ultimately reach water bodies and contribute to pollution problems. Research is needed to determine what impact reductions in losses of nitrogen and phosphorus from the field have on loadings to water bodies such as the Chesapeake Bay. EPIC estimates of losses are made on a per acre basis. Edge of field or root zone losses may never reach water bodies due to deposition on an adjoining acre of cropland or removal by buffer strips.

Another area overlooked in this study is the impact of nutrient planning on the nitrogen basis (input/output) of the farms. Further research is needed to determine what impact a change in livestock feed rations may have on the nutrient content of animal residues and on the ability to achieve nitrogen loss reductions. In this study, nutrient content of manure was assumed to be the average of previous manure tests on each of the case farms. However, nutrient content will vary with feed rations of livestock, handling, and storage practices.

While this study did estimate the change in phosphorus losses associated with reduction in nitrogen losses, it was not a focus of the study. Alternative fertilizer management practices were included in the model as a means to reduce nitrogen losses. Phosphorus losses were not restricted. As nitrogen loss restriction was tightened, phosphorus losses fluctuated. It is uncertain what impact a restriction on phosphorus losses would have on the costs of achieving nitrogen loss reductions.

Conclusions

This study provides an environmental and economic analysis of the ability to reduce potential nitrogen loadings to water bodies through the implementation of nutrient management plans. Study results indicate that nutrient management plans, by reducing excess applications of plant available nitrogen to cropland and pasture, do result in significant reductions while increasing farm income. Nutrient management plans on the four case farms reduced mean nitrogen losses by 23 to 45 percent per acre while increasing farm income. Nutrient management also resulted in reductions of phosphorus losses by up to 66 percent.

While reducing excess nitrogen applications achieved significant reductions in estimated losses, further reductions may be achieved through farm level planning in which fertilizer management practices and crop rotations are targeted within a farm based on susceptibility of soils to nutrient losses. Linear programming results for Farm 2 show that nitrogen losses could be reduced up to 44 percent below pre-plan losses with no impact on farm net economic returns. To achieve this reduction, crop rotations and fertilizer management practices are altered based on crop yields and susceptibility of soils to nitrogen loss. However, while initial reductions in nitrogen losses have little or no impact of farm returns, as nitrogen loss restrictions are tightened, the impact on farm income increases significantly. When crop rotations and fertilizer management practices are flexible, nitrogen losses can be reduced up to 52 percent below after plan loss. However, this reduction decreases farm net economic returns by 56 percent.. Even when crop rotations are restricted to current rotations and livestock numbers can not be reduced, nitrogen losses can be reduced up to 41 percent below pre-plan losses while decreasing after plan net economic returns by less than $200. The additional reductions in nitrogen losses beyond those seen after implementation of the nutrient management plan are achieved through the alternative routing of manure and commercial fertilizers within the farm.

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Appendix A: Southwestern Virginia Dairy

Soils

In using EPIC, each slope and soil type must be modeled individually. Therefore, in order to simplify the modeling process, the soils were narrowed down to Frederick, Groseclose, and Newark. Frederick and Groseclose are the predominant soils on the farm and are used to represent the small percentages of Poplimento, Slabtown, Lowell, and Lodi present. Newark will represent Lindside-Nolin. These soils were chosen based on soil maps of the farm and through consultation with soil scientists at Virginia Tech. In order to represent each of the slope classifications listed above, each soil is modeled for a 4.5 percent, 10.5 percent, and 16.5 percent slope. Although the 16.5 percent slope is generally not present in fields of corn or wheat, including the slope in the modeling process will be beneficial in illustrating the effect of slope on nutrient loss. The Newark soil is modeled for a one percent slope.

Weather

EPIC simulations for Farm 1 use internally generated weather based on parameters established for Pulaski County. These parameters were established by using actual weather data for Pulaski County during the period of 1953 to 1993. The daily weather data was input into a supplement to EPIC, WXPARM, which created the necessary parameters for EPIC to generate weather.

Crop Rotations

The modeling process has been limited to the rotation of rye cover, corn, and wheat. This is the area were the most change has occurred as a result of the nutrient management plan. Little has changed in the management of alfalfa and pasture.

Commercial Fertilizer and Manure Applications

The modeling of management practices before and after the nutrient management plan is the same with the exception of the change made in commercial nitrogen application. Although not all cropland received manure before the plan, it is assumed in the model that the application rate of manure remains the same on all cropland before and after the plan. This assumption is made due to difficulty in determining which land did not consistently receive manure. Prior to the adoption of the plan, decisions concerning manure applications were made by another member of the family.

Average manure nutrient values for Farm 1 were calculated using the results of manure tests provided by the farmer from August 1992, April 1993, September 1993, and January 1995 (see Table A.1.

Table A.1: Average Manure Nutrient Values for Farm 1 (lb./ 1000 gallons)

TKN	NH_4	P_2O_5	% Moisture
21.34	11.83	10.72	93.97

The time and rate of commercial nitrogen application is changed within the model to reflect the impact of the nutrient management plan. All fertilizer is surface applied. Before the plan, nitrogen is applied pre-plant. The application rate did not vary with soil conditions or manure application. Nitrogen was applied at a rate of 140 pounds per acre for corn, 100 pounds per acre for wheat, and 80 pounds per acre for barley. As a result of the nutrient management plan, nitrogen is now applied in split application. Corn receives 30 pounds per acre at planting while small grains receive no commercial fertilizer at planting. Corn receives a sidedress application ranging from 40 to 80 pounds per acre when 12 to 18 inches tall. Small grains receive an application of 60 to 70 pounds per acre at growth stage thirty. No changes have been made in phosphorus application. Manure is applied at a rate of 3000 gallons per acre in fall, spring, and sometimes in the winter.

After the plan is adopted, commercial nitrogen is applied with a split application. The rate of the second application is based on a nitrate quick test. Unfortunately, EPIC can not model this practice. It is not possible to have EPIC apply fertilizer at a specific time without specifying the rate of application. Therefore, a specific rate must be set. For wheat a median value of 65 pounds per acre is used. However, 80 pounds per acre is applied to corn. This high application rate was chosen because when the sidedress application rate is set at a median value of 60 pounds per acre, average annual crop yields decrease slightly suggesting that in some years, nitrogen application limits EPIC crop yield estimates. However, the farmer has not observed any change in crop yields resulting from the implementation of the plan. Increasing the application to 80 pounds per acre minimizes the change in yield estimated by EPIC. The times of the sidedress applications should correspond fairly well with the proper growth stage. Corn receives a sidedress application in mid-June while receives an application in late-March. Crop yields and nutrient yields as estimated by EPIC are shown in Tables A.2 and A.3.

Partial Budget Analysis

In developing the partial budget for Farm 1, it has been assumed that the adoption of the nutrient management plan has affected 250 acres of cropland. This is approximately the number of acres in the corn, small grain, rye cover rotation each year. As stated earlier, this is the primary rotation on the farm and little change has occurred in the management of alfalfa or pasture.

Although the time of nitrate quick tests and sidedress fertilizer applications varies with crop, it is assumed in the development of the partial budget that the test is performed once a year on each field[32]. Supplied needed for the test are values at $.05 per acre. For 250 acres, this totals $13. It has been estimated that sampling and testing 20 acres will take approximately 40 minutes. To test 250 acres it would therefore take 8.3 hours. Labor is valued at $8 per hour for a total cost of $67. The cost of sidedress fertilizer application was valued at a custom rate of $5 per acre for a total of $1250. Using the custom rate to estimate the cost of the sidedress application should account for not only the additional time required but also the additional wear and tear on equipment.

As noted previously, not all cropland consistently received manure applications. While this practices was not modeled with EPIC, an attempt was made to calculate the increase in costs associated the spreading of manure to all cropland. Through consultation with the current producer, it was determined that the most likely land not to receive manure consistently in the past is cropland in the furthest tract from the home farm. This tract of land consists of 141 acres of

[32] Information concerning costs of nitrate quick tests and sidedress applications were obtained through consultation with Russ Perkinson, Nutrient Management Program Manager, Department of Conservation and Recreation, Division of Soil and Water Conservation.

cropland. To determine the value of the extra time, fuel, and equipment wear associated with the further trip required to spread the manure, a custom rate of $40 per hour was used for hauling and spreading manure. It is assumed that three trips can be made in one hour for fields close to the manure pit and only two trips per hour can be made to farther fields. In each trip 3000 gallons of manure is hauled. Valued in such a fashion, the marginal cost for application of manure to more distant fields is $2.22 for 1000 gallons. The total cost to haul manure to the airport tract is approximately $940.

Although additional costs are incurred, some costs are simultaneously reduced. Commercial fertilizer use is reduced as a result of crediting manure for nutrient content. To calculate this saving, commercial nitrogen is valued at $.26 per pound. The implementation of the plan results in a reduction in commercial nitrogen application from 140 lb./ac to 90 lb./ac on corn, 100 lb./ac to 65 lb./ac on wheat, and 80 lb./ac to 60 lb./ac on barley for a total reduction of 10250 pounds annually. This produces a savings of $2665.

There has been no change in yield, therefore income has not changed. The net change in income is $395 indicating that the nutrient management plan increased net income.

Table A.2: Crop Yields and Nitrogen Losses Before Plan, Farm 1

	Corn Yield (T/ac)	Wheat Yield (Bu/ac)	Erosion (T/ac)	Volatilization (lb./ac)	N03 in runoff (lb./ac)	Org. N w/sed. (lb./ac)	Min. N sub. flow (lb./ac)	Min. N loss w/ percolate (lb./ac)	Total N (lb./ac)
Frederick Soil; 4.5% slope									
average	18.7	70.2	0.7	23.0	7.3	6.2	5.0	6.3	24.8
minimum	14.3	50.1	0.1	12.2	0.0	0.9	2.0	0.0	5.9
maximum	22.3	95.9	2.6	33.9	102.0	20.3	11.0	36.0	121.0
st.dev	1.9	9.0	0.5	8.1	11.3	4.1	1.6	5.6	15.2
Frederick Soil; 10.5% slope									
average	18.6	70.0	3.1	22.9	7.2	18.3	10.8	4.4	40.7
minimum	14.2	50.1	0.3	12.1	0.0	2.7	4.0	0.0	11.6
maximum	22.1	95.3	11.8	33.9	100.0	61.1	22.0	29.0	147.2
st.dev	1.9	8.8	2.3	8.1	11.4	12.1	3.7	4.2	21.1
Frederick Soil; 16.5% slope									
average	18.4	69.6	8.2	22.9	7.4	36.0	16.1	3.1	62.6
minimum	14.2	50.0	0.8	12.1	0.0	5.4	6.0	0.0	16.9
maximum	22.0	94.1	30.5	33.8	101.0	121.4	33.0	23.0	188.7
st.dev	1.9	8.7	6.1	8.1	11.8	23.4	5.6	3.0	31.4
Groseclose Soil; 4.5% slope									
average	18.8	67.0	0.6	28.3	6.2	6.1	3.7	6.6	22.6
minimum	15.0	43.5	0.0	13.9	0.0	0.5	2.0	1.0	5.5
maximum	22.1	95.6	2.5	42.8	99.0	23.8	7.0	41.0	120.6
st.dev	1.7	9.6	0.5	9.8	11.1	4.6	1.0	5.8	15.4
Groseclose Soil; 10.5% slope									
average	18.7	66.9	2.9	28.3	6.5	19.3	7.7	5.0	38.5
minimum	14.9	43.5	0.2	13.7	0.0	2.1	4.0	0.0	10.5
maximum	22.1	95.2	11.7	42.6	103.0	76.7	15.0	36.0	155.2
st.dev	1.7	9.5	2.4	9.8	11.6	14.3	2.5	4.7	22.8
Groseclose Soil; 16.5% slope									
average	18.6	66.8	8.1	28.3	6.9	39.7	11.5	3.8	61.8
minimum	14.9	43.6	0.5	13.5	0.0	4.1	4.0	0.0	15.8
maximum	22.1	94.7	33.1	42.9	109.0	154.0	22.0	32.0	201.4
st.dev	1.8	9.5	6.6	9.8	12.2	28.3	3.5	3.7	35.8
Newark Soil; 1% slope									
average	20.7	72.1	0.5	23.6	25.1	6.7	0.7	2.8	35.4
minimum	13.5	50.2	0.1	12.7	6.0	1.5	0.0	0.0	9.5
maximum	23.2	98.5	1.6	34.4	157.0	21.7	1.0	13.0	170.1
st.dev	1.6	9.8	0.3	8.4	22.0	3.6	0.4	2.7	24.3

Table A.3: Crop Yields and Nitrogen Losses After Plan, Farm 1

	Corn Yield (T/ac)	Wheat Yield (Bu/ac)	Erosion (T/ac)	Volatilization (lb./ac)	N03 in runoff (lb./ac)	Org. N w/sed. (lb./ac)	Min. N sub. flow (lb./ac)	Min. N loss w/ percolate (lb./ac)	Total N (lb./ac)
Frederick Soil; 4.5% slope									
average	18.4	67.2	0.7	23.9	4.3	6.2	2.6	2.7	15.8
minimum	14.2	42.4	0.1	13.6	0.0	0.9	1.0	0.0	3.9
maximum	21.4	86.5	2.7	33.9	64.0	20.1	5.0	10.0	83.5
st.dev	1.6	8.0	0.5	7.9	5.5	4.1	0.6	1.9	8.7
Frederick Soil; 10.5% slope									
average	18.3	66.9	3.1	23.9	4.3	18.3	5.0	2.1	29.7
minimum	14.2	42.0	0.3	13.4	0.0	2.6	3.0	0.0	8.6
maximum	21.3	86.3	12.1	33.9	64.0	60.7	9.0	8.0	115.3
st.dev	1.6	7.9	2.3	7.9	5.5	12.2	1.0	1.5	15.7
Frederick Soil; 16.5% slope									
average	18.2	66.6	8.1	24.0	4.3	36.1	7.4	1.6	49.4
minimum	14.1	41.4	0.8	13.1	0.0	5.2	4.0	0.0	12.3
maximum	21.2	85.8	31.3	33.8	64.0	121.1	13.0	7.0	156.6
st.dev	1.6	7.9	6.1	7.9	5.6	23.5	1.8	1.2	26.9
Groseclose Soil; 4.5% slope									
average	19.4	67.2	0.6	29.5	3.3	6.1	1.8	2.5	13.6
minimum	16.4	47.9	0.0	16.5	0.0	0.4	1.0	0.0	3.2
maximum	21.3	87.1	2.5	42.8	24.0	23.4	3.0	8.0	44.8
st.dev	1.0	7.9	0.5	9.4	3.2	4.6	0.5	1.5	7.3
Groseclose Soil; 10.5% slope									
average	19.4	67.1	2.9	29.5	3.4	19.2	3.8	2.0	28.5
minimum	16.4	47.9	0.2	15.9	0.0	2.0	2.0	0.0	6.3
maximum	21.3	87.0	11.7	42.6	26.0	76.1	5.0	6.0	92.1
st.dev	1.0	7.9	2.4	9.4	3.5	14.3	0.7	1.2	16.6
Groseclose Soil; 16.5% slope									
average	19.3	66.9	8.0	29.5	3.6	39.4	5.1	1.6	49.8
minimum	16.3	48.0	0.5	15.3	0.0	3.8	4.0	0.0	9.7
maximum	21.2	86.9	32.8	43.0	29.0	153.2	9.0	5.0	168.2
st.dev	1.0	7.8	6.6	9.4	3.7	28.2	0.9	1.0	30.4
Newark Soil; 1% slope									
average	20.3	68.9	0.5	24.4	15.6	6.7	0.0	1.6	23.9
minimum	18.2	49.6	0.1	13.5	3.0	1.4	0.0	0.0	7.4
maximum	22.2	90.7	1.5	34.4	53.0	21.4	1.0	7.0	68.3
st.dev	0.8	8.4	0.3	8.2	8.6	3.5	0.1	1.2	10.3

Table A.4: Partial Budget, Farm 1

Proposed change: Change in Application Rates of Manure and Commercial Nitrogen

Additional Costs ($)		Additional Income ($)	0
nitrate quick test		none	
Supplies	13		
Labor ($8/hr)	67		
Sidedress Application			
250 acres @ $5	1250		
Manure Spreading			
Custom Charge	940		
Reduced Income ($)	0	Reduced Costs ($)	
none		Commercial Nitrogen	2665
		10250 lb. @$.26/lb.	
A. Total annual additional costs and reduced income	$ 2270	B. Total annual additional income and reduced costs	$ 2665
			$ 2270
		Net change in profit (B-A)	$ 395

Appendix B: Shenandoah Valley Dairy

Soils

In using EPIC, each slope and soil type must be modeled individually. Therefore, in order to simplify the modeling process, the soils were narrowed down. This is necessary because five soil types are present on the farm and each soil has numerous slopes.[33] The soils were narrowed down to Frederick, Nixa, and Timberville. Frederick is the predominant soil on the farm and will be used to represent the Christian soil present. Timberville will be used to represent the small percentage of Fluvaquents. Although the Nixa soil comprises only a small percentage of the cropland, the distinctiveness of this soil warrants inclusion in the modeling process. Frederick soil is present on the farm in slopes ranging from 2 to 45 percent. In order to represent the four slope classifications (listed above), the soil is modeled for a 4.5 percent, 10.5 percent, 16.5 percent, and 26.5 percent slopes. The 16.5 and 26.5 percent slopes generally are not present in cropland. However, a few fields containing the corn, wheat, clover cover rotation do contain steep slopes and will therefore be modeled for the 16.5 percent slope. The modeling of the various slopes illustrates the effect of slope on nutrient loss. The Timberville soil is modeled with a two percent slope.

Weather

The EPIC simulations use internally generated weather data based on parameters established for Augusta county. These parameters have been established by using actual weather data for Augusta county during the period of 1953 to 1993. Although the weather created for each of the one hundred replications is different, the long-term statistical properties of the weather parameters are maintained in each simulation.

Commercial Fertilizer and Manure Applications

Before the implementation of the plan, semi-solid manure was spread on the home pasture and 38 acres of cropland. Home pasture received approximately 15 T/ac annually while fields H13 and H14 received approximately 8.4 T/ac annually.[34] The rest of the fields received only commercial fertilizer application. Prior to the adoption of nutrient management planning, the farm only had 85 dairy cows. However, dairy cow numbers have now increased to 160 (a factor of 1.88). However, this increase in livestock numbers is not a result of the nutrient management plan. Therefore, in an attempt to isolate the impacts of the plan, it will be assumed that manure production before the plan was also 1.88 times greater. For the EPIC simulations, it is assumed that all manure would have been applied to the same fields but at higher application rates.

Although H13 and H14 did receive manure, the manure was not credited for nitrogen content when applying commercial fertilizers. Commercial nitrogen application was the same as on all other

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[33] Each soil also varies by the amount of gravel present in different locations. Through consultation with Dr. James Baker (Department of Crop and Soil Environmental Sciences, VPI&SU) slope has been determined to more important in affecting nutrient loss. Based on this, the differences in the amount of gravel present within a specific soil will be ignored for now. However, the Nixa soil is extremely gravelly.

[34] Unless otherwise indicated, manure application rates are expressed on wet basis as spread.

cropland. However, H13 and H14 received no commercial phosphorus. Corn received 150 to 160 lb./ac nitrogen prior to planting, barley received 110 lb./ac in split applications, and rye received 40 lb./ac. Commercial phosphorus was applied at a rate of 50 lb./ac to barley and rye.

With the adoption of the plan, liquid manure is applied to cropland while commercial fertilizer applications are reduced. The reduction in commercial nitrogen applications are phased in with the implementation of two separate nutrient management plans. With the first plan, the phosphorus application of 50 lb./ac to small grains has been eliminated while the application of nitrogen to corn is reduced 150-160 lb./ac to 100 lb./ac and the nitrogen application to small grains is reduced from 110 lb./ac in split applications to a single application of 50 lb./ac in March.. Tillage remains the same. Home pasture receives semi-solid manure at a rate of approximately 5 T/ac annually in addition to 40 lb./ac commercial nitrogen each spring. Manure is not incorporated. With the implementation of the current nutrient management plan, commercial nitrogen application is reduced to 40-60 lb./ac while all other fertilizer applications remain unchanged.

Values used in EPIC for nutrient content of liquid manure are based on an average of nutrient values obtained from manure tests for the farm over the period of April 1988 to May 1995. Nutrient values used for semi-solid manure were obtained from the Nutrient Management Handbook because no test results were available from the farm. These values are average values for semi-solid beef manure tested in Virginia during the period of January 1989 to November 1992. Nutrient content values are shown in Table B.1. Crop yields and nutrient losses as estimated by EPIC are shown in Tables B.2 - B.8.

Table B.1: Manure Nutrient Content, Farm 2

Manure Type	TKN	NH_4	P_20_5	% MOISTURE
Liquid Dairy Manure	25.85	13.23	12.23	93.92
Semi-solid Manure	12.79	2.57	6.67	73.08

Partial Budget Analysis

In order to examine the impact of the nutrient management plan on farm income, a partial budget has been developed for Farm 2. Several assumptions were made in the development of this budget. First, the changes in costs and farm income resulting from the changes in rotations will not be considered. Although the changes in rotations coincided with the adoption of the nutrient management plan, the changes were not part of the plan. Crop rotation changes were made for pest management. Second, changes in income due to changes in crop yield are not considered. The change in crop yields (as reported by EPIC) are small.

The additional costs resulting from the adoption of new management practices with the implementation of the initial plan are calculated first (see Table B.9). These practices include the spreading of manure to cropland rather than pasture and also the addition of commercial nitrogen applied to home pasture. To determine the cost of spreading manure on cropland, the cost of constructing the pit and purchase of the pump and tank spreader must be calculated. The manure pit cost approximately $14,000. Cost share covered $11,000 leaving the farmer with a cost of $3,000. The pit is valued over a life of 20 years with an annual depreciation is $150. Annual maintenance costs are approximately $200 while the increase in property tax and insurance totals approximately $100 annually. Using an interest rate of 6 percent, annual interest costs are $90 resulting in a total annual cost for the manure pit of $540. The tank spreader cost $9,000. However, a 25 percent state income tax credit was received for this purchase resulting in a cost of approximately $6,750. The spreader is valued over a life of 8 years resulting in an annual depreciation of $844. Using an interest rate of 6 percent, annual interest costs are $203. Annual maintenance costs are approximately $200 while the increase in insurance and property tax is calculated as 0.5% of the initial cost resulting in a total annual cost of $1,292 for the spreader. The pump cost approximately $9500 . Valued over a life of 8 years, this results in an annual depreciation of $1188. Annual interest cost are $285 while maintenance costs are approximately $200. The increase in taxes and insurance is calculated as 0.5 percent of the initial cost resulting in a total annual cost of $1,721 for the pump.

Manure is spread on the fields closer to the pit by the producer. Application to farther fields is handled by a custom hauler. Manure is applied twice a year. Two trucks are custom hired for one day of approximately 12 hours. Using a rate of $40 per hour results in a total cost of approximately $1920. The cost of time and fuel associated with the spreading of manure by the producer must also be calculated. Approximately three loads of manure (approx. 300 gallons each load) can be applied to in one hour. Allowing for an application rate of 6,000 gallons per acre to both corn and small grain, manure application would take approximately 80 hours annually. Valued at $8 per hour results in a cost of $640 annually. A 150 hp tractor is used to haul manure while a 100 hp tractor is used to run the pump. Both tractors run continuously when manure is being applied. Diesel fuel is valued at $1.00 per gallon. The amount of fuel used in gallons per hour is calculated using the results of data found from tractor tests at the University of Nebraska.[35] Lubrication and filters are calculated at fifteen percent of fuel costs. This results in a total cost of $1,012 for fuel and lubrication.

One other additional cost must be included in the budget. With the removal of manure from pasture, commercial nitrogen is applied to the home pasture at a rate of 40 lb./ac. This totals 2,000 lb. which are valued at the rate of $.26 per pound resulting in an additional cost of $520.

With the installation of the pit, the practice of hauling manure daily was stopped and the amount of commercial fertilizer used was reduced. Manure is still scraped on a daily basis, however, rather than immediately being applied to land it is stored in the manure pit. The decrease in cost resulting from no longer hauling manure daily is calculated in the reduced time required, and the longer life of the box spreader. A box spreader is still used, but the life of a spreader is now 10 years as opposed to two. A spreader costs approximately $8,000. With a two year life, the depreciation would be $4,000 while extending the life to 10 years reduces the depreciation to $800, a savings of $3,200. Spreading the manure onto the land closest to the barn took approximately one hour a day. Valued at $8/hr, the total reduced cost of labor is $2,920.

Spreading manure on cropland also allowed for a reduction in the amount of commercial fertilizers used in crop production. Reducing the application of commercial nitrogen to corn from 100-110 pounds per acre and the application to small grains by 60 pounds per acre results in an annual reduction of 15,140 pounds of nitrogen. Valued at $.26 per lb. the reduced annual cost of nitrogen totals $3,936. Commercial phosphorus application crops is eliminated resulting in an annual reduction of 4,600 pounds. Valued at $.25 per lb. this totals $1,150. Since the changes in crop rotation will not be considered in this budget and crop yields did not change, there is no change in

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[35] Ronald D. Kay. *Farm Management: Planning, Control, and Implementation.* Second Edition. McGraw-Hill, Inc., US, 1986. p312.

income. The net change in income with the implementation of the nutrient management plan is $3,563

Table B.2: Crop Yields and Nitrogen Losses Before Plan; Corn, Barley, Sudex Rotation

	Corn Yield (T/ac)	Barley Yield (T/ac)	Sudex Yield (T/ac)	Erosion (T/ac)	Volatil -ization (lb./ac)	NO3 in runoff (lb./ac)	Org. N w/ sed. (lb./ac)	Min. N sub. flow (lb./ac)	Min. N w/ percolate (lb./ac)	Total N loss (lb./ac)
Frederick Soil; 4.5% slope										
average	18.72	10.48	5.06	1.09	21.03	5.89	9.00	4.65	8.82	28.36
minimum	13.81	7.71	2.85	0.10	18.43	1.00	1.01	3.00	1.00	6.83
maximum	22.66	13.47	6.79	3.44	28.13	66.00	30.88	8.00	43.00	87.41
st.dev	1.98	1.35	0.94	0.67	1.19	7.08	4.83	0.88	8.47	14.36
Frederick Soil; 10.5% slope										
average	18.50	10.48	5.00	4.89	21.03	5.93	26.80	9.98	6.71	49.41
minimum	13.75	7.71	2.78	0.38	18.35	0.00	2.63	5.00	1.00	15.63
maximum	22.33	13.47	6.73	15.35	28.20	74.00	91.45	16.00	36.00	119.45
st.dev	1.90	1.35	0.95	3.04	1.21	7.73	14.44	2.25	6.95	22.11
Timberville Soil; 2% slope										
average	18.49	10.19	5.20	0.47	20.71	6.26	5.88	2.05	18.92	33.11
minimum	13.58	7.67	2.97	0.05	18.16	1.00	0.66	1.00	2.00	6.87
maximum	22.65	13.35	7.01	1.35	28.02	79.00	18.84	3.00	62.00	95.73
st.dev	2.01	1.32	0.96	0.28	1.43	7.80	3.04	0.50	14.20	18.20

Table B.3: Crop Yields and Nitrogen Losses Before Plan; Corn, Barley, Corn, Rye Cover

	Corn Yield (T/ac)	Barley Yield (T/ac)	Erosion (T/ac)	Volatil -ization (lb./ac)	NO3 in runoff (lb./ac)	Org. N w/ sed. (lb./ac)	Min. N sub. flow (lb./ac)	Min. N w/ percolate (lb./ac)	Total N loss (lb./ac)
Frederick Soil; 4.5% slope									
average	17.8	9.9	1.6	0.0	6.8	8.6	4.9	5.2	25.6
minimum	9.9	7.3	0.1	0.0	0.0	0.6	3.0	0.0	9.2
maximum	22.8	12.7	4.3	0.0	76.0	24.6	8.0	29.0	96.2
st.dev	2.7	1.3	0.8	0.0	9.3	4.1	1.0	4.7	13.0
Frederick Soil; 10.5% slope									
average	17.6	9.9	7.1	0.0	6.9	25.6	11.3	3.9	47.7
minimum	9.7	7.3	0.3	0.0	0.0	1.4	7.0	0.0	16.0
maximum	22.7	12.7	20.7	0.0	80.0	74.9	19.0	25.0	123.0
st.dev	2.7	1.3	3.6	0.0	9.5	12.4	2.3	3.7	19.5
Timberville Soil; 2% slope									
average	17.3	9.6	0.7	0.0	7.2	6.1	2.2	13.4	28.9
minimum	9.4	7.0	0.0	0.0	1.0	0.4	1.0	1.0	8.5
maximum	22.7	12.6	1.7	0.0	85.0	16.2	4.0	50.0	105.9
st.dev	2.6	1.3	0.3	0.0	9.6	2.8	0.5	9.9	15.5
Nixa Soil; 4.5% slope									
average	10.1	6.7	0.1	0.0	2.8	3.1	11.1	103.5	120.5
minimum	4.2	2.8	0.0	0.0	0.0	0.1	6.0	28.0	37.0
maximum	15.0	9.3	0.6	0.0	67.0	13.8	17.0	169.0	231.6
st.dev	2.0	1.3	0.1	0.0	8.6	2.2	2.4	28.2	32.4
Nixa Soil; 10.5% slope									
average	10.2	6.7	0.7	0.0	4.2	11.7	22.9	87.2	126.0
minimum	4.3	2.8	0.1	0.0	0.0	1.0	12.0	26.0	45.5
maximum	15.0	9.3	2.9	0.0	88.0	44.2	35.0	148.0	233.1
st.dev	1.9	1.3	0.5	0.0	12.3	7.3	4.9	25.0	32.7

Table B.4: Crop Yields and Nitrogen Losses Before Plan; Corn, Rye Cover Rotation

	Corn Yield (T/ac)	Erosion (T/ac)	Volatilization (lb./ac)	NO3 in runoff (lb./ac)	Org. N loss w/sediment (lb./ac)	Min. N sub. flow (lb./ac)	Min. N w/percolate (lb./ac)	Total N loss (lb./ac)
Frederick Soil; 10.5% slope								
average	19.0	5.8	0.0	6.6	23.6	11.4	3.7	45.3
minimum	12.0	0.4	0.0	0.0	1.9	6.0	0.0	13.9
maximum	23.4	17.6	0.0	80.0	68.7	19.0	26.0	119.5
st.dev	2.1	3.0	0.0	8.9	11.4	2.4	3.6	18.3
Frederick Soil; 16.5% slope								
average	18.9	15.2	0.0	6.9	46.4	16.7	2.7	72.7
minimum	12.0	1.1	0.0	1.0	3.9	10.0	0.0	18.9
maximum	23.2	46.9	0.0	84.0	131.6	28.0	22.0	163.6
st.dev	2.1	8.0	0.0	9.3	22.3	3.6	2.8	28.5
Nixa Soil; 10.5% slope								
average	10.4	0.6	0.0	2.9	10.2	22.8	90.9	126.8
minimum	4.7	0.0	0.0	0.0	0.9	12.0	21.0	43.8
maximum	15.1	2.3	0.0	70.0	36.9	38.0	174.0	230.0
st.dev	2.0	0.4	0.0	7.5	6.5	4.7	27.3	34.4

Table B.5: Crop Yields and Nitrogen Losses Before Plan; Pasture

	Pasture Yield (T/ac)	Erosion (T/ac)	Volatilization (lb./ac)	NO3 in runoff (lb./ac)	Org. N loss w/sediment (lb./ac)	Min. N sub. flow (lb./ac)	Min. N w/ percolate (lb./ac)	Total N loss (lb./ac)
Frederick Soil; 4.5% slope								
average	0.5	0.5	39.3	1.2	13.9	1.2	12.8	29.1
minimum	0.4	0.0	8.9	0.0	1.0	0.0	0.0	3.2
maximum	0.7	1.7	68.0	13.0	50.1	3.0	37.0	65.6
st.dev	0.1	0.4	10.3	1.4	9.3	0.4	9.9	12.6
Frederick Soil; 10.5% slope								
average	0.5	2.4	39.2	1.1	41.2	2.8	12.0	57.1
minimum	0.4	0.1	3.1	0.0	2.5	1.0	0.0	6.1
maximum	0.6	8.7	75.4	12.0	164.9	5.0	34.0	173.9
st.dev	0.1	1.7	11.0	1.3	27.2	0.8	9.5	27.8
Frederick Soil; 16.5% slope								
average	0.5	6.3	39.3	1.3	81.8	4.0	10.9	97.9
minimum	0.4	0.3	9.1	0.0	6.4	2.0	0.0	9.4
maximum	0.6	30.6	69.2	13.0	305.9	7.0	30.0	314.9
st.dev	0.1	4.7	10.2	1.4	53.8	0.9	8.9	53.7
Frederick Soil; 26.5% slope								
average	0.5	21.2	39.1	1.4	172.3	5.4	9.4	188.5
minimum	0.4	1.6	5.7	0.0	17.4	2.0	0.0	21.4
maximum	0.7	84.4	68.3	12.0	566.6	11.0	29.0	579.6
st.dev	0.1	15.0	10.9	1.4	100.5	1.4	7.9	100.7

Table B.6: Crop Yields and Nitrogen Losses After Plan; Corn, Barley, Soybean Rotation

	Corn Yield (T/ac)	Soybean Yield (T/ac)	Barley Yield (Bu/ac)	Erosion (T/ac)	Volatil-ization (lb./ac)	NO3 in runoff (lb./ac)	Org. N w/ sed. (lb./ac)	Min. N sub. flow (lb./ac)	Min. N percolate (lb./ac)	Total N loss (lb./ac)
Frederick Soil; 4.5% slope										
average	18.7	42.1	10.5	1.5	33.6	4.7	10.6	3.3	3.1	21.7
minimum	13.8	25.5	7.7	0.1	0.0	0.0	0.8	1.0	0.0	4.9
maximum	22.4	57.1	13.3	4.2	69.2	29.0	38.5	7.0	14.0	54.5
st.dev	1.9	7.4	1.3	0.8	32.9	3.4	5.7	1.2	2.4	9.1
Frederick Soil; 10.5% slope										
average	18.5	41.7	10.5	6.6	33.6	4.7	31.4	6.9	2.4	45.4
minimum	13.7	25.1	8.0	0.4	0.0	0.0	2.0	3.0	0.0	10.3
maximum	22.4	57.3	13.3	19.5	69.2	31.0	113.6	16.0	12.0	135.6
st.dev	1.9	7.4	1.3	3.5	32.9	3.5	16.9	2.8	1.9	20.3
Timberville Soil; 2% slope										
average	18.5	42.2	10.2	0.6	33.1	4.9	7.0	1.5	8.2	21.5
minimum	13.6	27.1	7.7	0.0	0.0	0.0	0.6	1.0	1.0	5.5
maximum	22.6	57.0	13.3	1.7	69.0	25.0	22.7	3.0	37.0	55.7
st.dev	2.0	7.2	1.3	0.3	32.5	3.3	3.5	0.5	6.2	9.6
Nixa Soil; 4.5% slope										
average	11.1	24.6	6.3	0.1	32.0	1.7	3.4	6.2	59.9	71.2
minimum	6.2	12.3	3.1	0.0	0.1	0.0	0.1	1.0	13.0	16.3
maximum	15.2	39.6	8.4	0.6	65.2	42.0	18.0	13.0	155.0	176.0
st.dev	1.6	5.2	1.1	0.1	30.8	3.2	2.5	3.4	33.6	38.5
Nixa Soil; 10.5% slope										
average	11.1	24.5	6.3	0.7	32.2	2.1	13.2	12.8	51.4	79.4
minimum	6.8	12.0	3.1	0.1	0.0	0.0	1.0	3.0	12.0	20.9
maximum	15.2	39.6	8.5	3.0	66.0	43.0	56.0	30.0	134.0	191.3
st.dev	1.6	5.3	1.1	0.5	30.8	3.2	8.5	7.4	27.1	39.0

Table B.7: Crop Yields and Nitrogen Loss After Plan; Corn, Wheat, Clover Cover Rotation

	Corn Yield (T/ac)	Wheat Yield (T/ac)	Erosion (T/ac)	Volatilization (lb./ac)	NO3 in runoff (lb./ac)	Org. N w/sediment (lb./ac)	Min. N sub. flow (lb./ac)	Min. N w/percolate (lb./ac)	Total N loss (lb./ac)
Frederick Soil; 10.5% slope									
average	17.8	10.5	5.2	33.8	3.7	25.0	5.8	1.3	35.7
minimum	12.2	8.0	0.2	0.0	0.0	1.8	3.0	0.0	8.6
maximum	21.5	13.0	19.4	69.3	30.0	116.2	13.0	12.0	134.2
st.dev	1.9	1.3	3.5	33.0	3.2	16.4	1.9	1.8	18.9
Frederick Soil; 16.5% slope									
average	17.5	10.5	13.6	33.8	3.8	49.9	8.8	0.9	63.4
minimum	12.0	7.9	0.5	0.0	0.0	4.1	4.0	0.0	14.0
maximum	21.3	13.0	51.0	69.3	33.0	224.2	21.0	9.0	247.2
st.dev	1.9	1.3	9.1	32.9	3.4	32.3	2.9	1.4	34.8
Nixa Soil; 10.5% slope									
average	11.1	5.9	0.6	32.4	1.8	11.0	11.3	42.5	66.5
minimum	7.7	2.6	0.0	0.2	0.0	0.2	4.0	9.0	22.1
maximum	14.5	8.5	3.1	66.3	43.0	56.5	27.0	115.0	158.1
st.dev	1.5	1.1	0.5	30.8	3.2	8.1	5.6	17.7	26.8

Table B.8: Crop Yields and Nitrogen Losses After Plan; Pasture

	Pasture Yield (T/ac)	Erosion (T/ac)	Volatilization (lb./ac)	NO3 in runoff (lb./ac)	Org. N loss w/sediment (lb./ac)	Min. N sub. flow (lb./ac)	Min. N w/ percolate (lb./ac)	Total N loss (lb./ac)
Frederick Soil; 4.5% slope								
average	0.5	0.5	9.5	1.0	5.5	1.4	14.2	22.1
minimum	0.4	0.0	1.1	0.0	0.5	1.0	1.0	3.1
maximum	0.6	1.8	17.8	7.0	18.2	3.0	38.0	47.6
st.dev	0.1	0.4	2.9	1.1	3.6	0.5	9.2	9.5
Frederick Soil; 10.5% slope								
average	0.5	2.4	9.6	1.0	16.4	3.2	13.2	33.8
minimum	0.3	0.1	1.1	0.0	1.2	1.0	1.0	6.8
maximum	0.6	8.7	17.8	4.0	59.7	5.0	36.0	77.2
st.dev	0.1	1.7	3.0	1.0	10.8	0.9	9.0	13.5
Frederick Soil; 16.5% slope								
average	0.5	6.6	9.6	1.1	32.6	4.5	12.1	50.3
minimum	0.3	0.4	1.2	0.0	2.5	2.0	0.0	8.5
maximum	0.6	23.7	17.7	5.0	106.0	8.0	33.0	125.6
st.dev	0.1	4.7	2.7	1.0	20.9	1.0	8.5	22.3
Frederick Soil; 26.5% slope								
average	0.5	23.0	9.6	1.3	76.2	6.4	10.5	94.4
minimum	0.3	1.7	1.3	0.0	7.3	3.0	0.0	13.3
maximum	0.6	88.1	17.7	8.0	257.8	13.0	29.0	275.8
st.dev	0.1	16.2	2.7	1.2	46.1	1.8	7.5	47.2

Table B.9: Partial Budget, Farm 2[a]

Proposed change: Adoption of First Nutrient Management Plan

Additional Costs ($)		Additional Income ($)	0
Manure spreading			
labor @ $8/hr	640		
fuel and lubrication	1012		
custom charge	1920		
Tank Spreader			
depreciation	844		
interest	203		
maintenance	200		
insurance and taxes	45		
Pump			
depreciation	1188		
interest	285		
maintenance	200		
insurance and taxes	48		
Earthen Manure Pit			
depreciation	150		
interest	90		
maintenance	200		
insurance and taxes	100		
Commercial Nitrogen	520		
2000 lb. @$.26			
Reduced Income ($)	0	Reduced Costs ($)	
		Commercial Nitrogen	3936
		15,140 lb. @$.26/lb.	
		Commercial Phosphorus	1150
		4600 lb. @$.25/lb.	
		Scrap and Haul	
		box spreader	3200
		labor @$8/hr	2920
A. Total annual additional costs and reduced income	$ 7643	B. Total annual additional income and reduced costs	$ 11206
			$ 7643
		Net change in profit (B-A)	$ 3563

[a] Tax effects are not included in partial budget with the exception of a 25% tax credit received on tank spreader.

Appendix C: Southeastern Virginia Crop and Swine

Soils

Due to the great variation in soil characteristics, it was determined that no soils could be excluded. Therefore, all crop rotations are modeled on Emporia, Kinston, Peawick, Rumford, Slagle, and Uchee. Pasture is modeled on Chickahominy, Kinston, Peawick, and Slagle.

Weather

The simulations use internally generated weather data which is based on parameters established for Holland, VA. The weather parameters are established using actual daily weather data for Holland during the period of 1953 to 1992. Although the weather created by EPIC for each of the one hundred, four year rotations is different, the long term statistical properties of the weather parameters are maintained. The sequence of weather used for each set of one hundred simulations is identical.

Crop Rotations

While a cotton rotation was implemented about the same time as the plan, it will be assumed in the model that cotton has always been grown. However, there will be no change in tillage or nitrogen application practices used for cotton with the implementation of the plan in the model.

Commercial Fertilizer and Manure Applications

The modeling of management practices before and after the nutrient management plan is the same with the exception of the changes in fertilizer applications. The crediting of manure for nutrient content has been accompanied by a reduction of commercial fertilizer. The total amount of nitrogen applied to crops, including nitrogen from both manure and legume carryover, has been reduced. For example, the application to corn was reduced from 165 pounds commercial nitrogen (in addition to manure application) to 110 pounds of nitrogen including commercial fertilizers, legume carryover, and manure nitrogen content. Manure applied to corn is injected at a rate of 3,000 gallons per acre prior to planting. The recommended application of commercial nitrogen is 15 pounds while soybeans are credited with a residual of 15 pounds of nitrogen. This results in a total application to corn of approximately 110 pounds. Wheat has a recommended application of approximately 10 pounds per acre when manure is also applied. Including a credit of 40 pounds residual per acre from peanuts, total nitrogen application to wheat is approximately 100 pounds of nitrogen. In the past, application of nitrogen to wheat was at least 125 pounds of commercial nitrogen. Management of legumes has not changed. No fertilizer is applied to soybeans or peanuts. Total nitrogen application to cotton is 75 pounds including the residual from soybeans. Soybean residual is credited for 10 pounds of nitrogen. Commercial nitrogen is applied at a rate of 65 pounds per acre. No manure is applied to cotton. Fertilizer application to cotton has not changed with the implementation of the plan. Lime is applied once every three years to either cotton or corn at a rate of approximately 1 ton per acre. No commercial phosphorus is applied to crops. Before the plan, most crops received 30 to 60 pounds commercial phosphorus per acre.

Manure was applied to approximately 50 acres of corn nearest the lagoon before the adoption of the nutrient management plan. However, the manure was not credited with nutrient content due to uncertainty. The nutrients in the manure were applied in addition to the commercial nitrogen application rates stated above. With the construction of the slurry storage and hog houses, hog production increased by a factor of 4.1 on an annual basis. However, this increase in production was not a result of the nutrient management plan. Therefore, in an attempt to isolate the impacts of the plan, it will be assumed that manure production before the plan was also 4.1 times greater. A set of one hundred simulations will be run for both scenarios, with and without manure, existing before the implementation of the plan.

No commercial phosphorus is applied to crops. However, before the implementation of the plan, phosphorus is applied at a rate of 40 pounds per acre to corn, wheat, and cotton.

Annual production of manure currently is approximately 748,253 gallons. However, if manure is applied to all crops and pasture at rates stated in the nutrient management plan, 1,393,600 gallons of manure could be utilized on an annual basis. Therefore, manure can not be applied to all crops. Currently manure is applied to all wheat and corn while cotton receives none.

Manure is currently applied to rye following corn at a rate of 1000 gallons per acre. Before the implementation of the nutrient management plan, rye received no fertilizer.

Pasture currently receives 1000 gallons per acre of manure in August in addition to commercial nitrogen applications of 30 pounds per acre in both July and August. Before the adoption of the plan, commercial nitrogen applications were the same, however, no manure was applied. All pasture affected by the plan is a combination of clover and fescue. Unfortunately, a limitation of EPIC is the inability to model two crops grown simultaneously within the same field. In an attempt to deal with this problem, pasture will be modeled individually as clover and fescue. Nitrogen loss attributed to pasture will be a simple average of the results of the two separate simulations.

Nutrient values of manure for the model were obtained from the Nutrient Management Handbook because no test results were available from the farm. These values are average values for manure tested in Virginia during the period of January 1989 to November 1992. Nutrient content values are shown in Table C.1.

Table C.1: Manure Nutrient Content, Farm 3

Manure Type	TKN	NH_4	P_20_5	% MOISTURE
Manure Slurry	41.13	26.93	29.75	94.97
Lagoon Manure	10.04	5.34	5.68	99.01

Crop Yields

While the reduction of nitrogen loss is significant, the change in management practices also has an impact on crop yields. Corn yields decreased from less than 1/2 bushel per acre up to 4 bushels per acre, depending on soil, resulting in a total decrease in corn of 172 bushels (see Tables 4,5, and 7). However, the most significant impact on yields is seen with wheat. With the reduction in fertilizer application, wheat yields are reduced by up to 5.3 bushels per acre resulting in an overall reduction of 587 bushels (see Tables 4, 5, 6, 7, and 8). Cotton, peanut, and soybean yields change only slightly.

While the impact of the plan on corn and wheat yields may seem significant, particularly for corn and wheat yields, these changes in crop yield may be overestimated due to the inability of EPIC to simulate tissue tests and nitrate quick tests. These test are used to determine the rate of the second application of nitrogen to corn and wheat. In EPIC, commercial nitrogen application levels after the plan are set at the level of application recommended in the nutrient management plan. In reality, if test results showed that additional nitrogen was needed, it could be applied. While this may minimize the impact of the plan on yield, an increase in commercial nitrogen application would also likely increase nitrogen losses. Crop yields and nutrient losses are shown in Tables C.2 - C.8.

Partial Budget Analysis

To determine the cost of spreading manure, the cost of the constructing the manure pit and purchase of the pump and honey wagon must be calculated. The slurry storage costs $125,500 while no cost share was received. The slurry storage is valued over a 30 year life resulting in an annual depreciation of $4,183. Annual maintenance cost of the storage facility is calculated as 0.5 percent of new cost resulting in a cost of $628[36]. Annual insurance costs are also calculated as 0.5 percent of the initial cost of the storage facility. Using an interest rate of 6 percent, annual interest costs on the average value are $3,765. The pump cost $4,500 and is valued over a life of 8 years. This results in an annual depreciation of $562. Again, insurance costs are calculated as 0.5 percent of the initial cost resulting in an annual cost of $23. Maintenance of the pump is valued at $113, 2.5 percent of the original cost. Using an interest rate of 6 percent, annual interest costs for the pump are $135. The cost of the honey wagon is $16,000. The honey wagon is valued over a life of 8 years resulting in an annual depreciation of $2,000. Annual insurance cost is $80 while maintenance is valued at $400. Using an interest rate of 6 percent, annual interest costs for the pump are $480. Taxes will not be increased since the additional equipment is used to better manage the disposal of wastes.

Loading, hauling, and spreading manure on the surface takes approximately 30 minutes per 4,000 gallons. When manure is injected, the time increases to about one hour per 4,000 gallons. Allowing for 3000 gallons per acre applied to corn (injected), 2000 gallons per acre surface applied to wheat, and 1000 gallons per acre surface applied to pasture and rye following corn, manure application would take 117 hours annually. Valued at a cost of $8 per hour, labor costs total $939. A 145 hp tractor is used to haul manure while a 130 hp tractor is used to run the pump. Both tractors run continuously when manure is being applied. Diesel fuel is valued at $.68 per gallon. The amount of fuel used in gallons per hour is calculated using the results of data found from tractor tests at the University of Nebraska.[37] Lubrication and filters are calculated at fifteen percent of fuel costs. This results in a total cost of $1,107 for fuel and lubrication.

With the reduction of commercial fertilizer application to crops, yields do decrease. Therefore, the reduction is income must also be calculated. Prices for crop yields are five year averages (1989-1993) obtained from Virginia Agricultural Statistics. Corn yield is reduced by up to 4 bushels per acre resulting in a total reduction of 172 bushels. Valued at $2.52 per bushel this results in a total reduction of $433.44. Wheat yield decreases by up to 5 bushels per acre for a total reduction of 591 bushels. Valued at $2.98 per bushel, the decline in wheat yield results in a reduction of income of $1761.18. Cotton, soybean, and peanut yields change only slightly and will not be considered

[36] Annual insurance and maintenance costs of slurry storage, pump, and honey wagon are based on percentages found in Fulhage, Charles. "Economic Comparison of Two Dairy Manure Management Systems." *Liquid Manure Application Systems: Design, Management, and Environmental Assessment.* Proceedings from the Liquid Manure Application Systems Conference. Rochester, NY. December 1 and 2, 1994.

[37] Ronald D. Kay. *Farm Management: Planning, Control, and Implementation.* Second Edition. McGraw-Hill, Inc., US, 1986. p312.

in the budget. The total reduction of income resulting from a decrease in crop yields is $2195. The nitrate quick tests and soil tests used to determine nitrogen applications to corn and wheat were both used before the implementation of the plan. Therefore the costs of these tests are not included in the partial budget.

With the construction of the manure slurry, the application of commercial fertilizers was reduced. With the application of manure, commercial nitrogen applied to corn was reduced from 165 pounds per acre to 15 pounds per acre. The 40 pound application of phosphorus was eliminated. With approximately 67.2 acres in corn on an annual basis, this results in a reduction of nitrogen by 10,080 pounds and a phosphorus reduction of 2,688 pounds. Commercial nitrogen to wheat is reduced from 125 pounds per acre to 15 pounds while phosphorus application is again eliminated. Each year, 201.6 acres are planted to wheat resulting in a nitrogen reduction of 22,176 pounds and a phosphorus reduction of 8,064 pounds. Phosphorus application to cotton is also eliminated resulting in a reduction of 5,376 pounds. In total, nitrogen is reduced by 32,256 pounds while phosphorus is reduced by 16,128 pounds. Nitrogen is valued at $.26 per pound resulting in a reduced cost of $8,387. Phosphorus is valued at $.25 per pound resulting in total reduction of $4,032.

With the construction of the manure pit and the purchase of equipment to spread manure, it was no longer necessary to custom hire to pump the lagoon. The lagoon was pumped once a year onto the 50 acres nearest the lagoon. The cost to have this done in 1991 was $1,487 while in 1992 it was $1,094 for an average of $1290.50.   However, as stated before, hog production is now 4.1 times greater than before the plan. In order to better examine the impact of the plan rather than the impact of an expansion on costs, previous manure production is assumed to also be 4.1 times larger. Therefore, the average cost of pumping the lagoon is also increased by a factor of 4.1 resulting in a total cost of $5,291.

The net change in income is $473 indicating that the nutrient management plan increased net income.

Table C.2: Crop Yields and Nutrient Losses Before Plan; Corn Rotation No Manure

	Corn Yld (lb./ac)	Peanut Yld (lb./ac)	Wheat Yld (Bu/ac)	Soybean Yld (Bu/ac)	Erosion (T/ac)	Volatil-ization (lb./ac)	N03 runoff (lb./ac)	Org. N w/sediment (lb./ac)	Min. N subsurface flow (lb./ac)	Min. N percolate (lb./ac)	Total N loss (lb./ac)
Emporia Soil, 1% slope											
Average	131.6	3810.1	64.0	42.3	0.3	0.0	10.1	2.7	1.6	8.1	22.6
Minimum	172.1	4496.5	84.9	58.5	1.0	0.0	55.0	7.4	3.0	37.0	71.5
Maximum	29.9	2784.7	41.6	20.1	0.0	0.0	0.0	0.3	1.0	0.0	4.3
st. dev	25.2	363.4	8.9	9.4	0.2	0.0	12.0	1.3	0.5	6.2	12.7
Emporia Soil, 4.5% slope											
Average	131.0	3793.4	64.0	41.7	1.7	0.0	10.3	9.0	5.9	5.8	31.0
Minimum	172.3	4497.8	84.7	58.3	5.0	0.0	54.0	23.6	11.0	35.0	83.9
Maximum	28.8	2760.6	41.6	19.1	0.2	0.0	1.0	1.0	3.0	0.0	8.1
st. dev	25.4	366.9	8.9	9.6	0.9	0.0	12.0	4.4	1.6	5.0	13.7
Kinston Soil, 2% slope											
Average	101.6	3660.1	50.5	35.3	0.6	0.0	9.5	10.5	1.1	11.7	32.7
Minimum	162.5	4497.2	74.6	53.3	2.0	0.0	59.0	27.6	2.0	50.0	81.6
Maximum	9.6	2638.2	27.6	17.8	0.1	0.0	1.0	1.3	0.0	0.0	6.3
st. dev	33.4	396.2	10.1	9.4	0.4	0.0	10.7	5.5	0.3	8.5	15.0
Peawick Soil, 1% slope											
Average	96.7	3629.4	43.4	34.2	0.4	0.0	9.6	2.6	1.0	11.9	25.1
Minimum	151.7	4501.8	64.2	49.5	1.1	0.0	55.0	6.8	1.0	52.0	69.4
Maximum	10.2	2681.8	22.5	16.2	0.1	0.0	1.0	0.3	0.0	1.0	7.3
st. dev	30.5	406.4	8.8	7.8	0.2	0.0	10.6	1.3	0.2	7.9	12.1
Peawick Soil, 4.5% slope											
Average	96.2	3609.0	43.4	34.0	2.0	0.0	9.4	8.5	3.5	10.0	31.4
Minimum	151.7	4499.3	64.4	49.6	5.5	0.0	55.0	21.6	5.0	48.0	80.9
Maximum	10.0	2654.9	21.9	16.2	0.2	0.0	1.0	1.1	2.0	1.0	9.4
st. dev	30.7	406.2	8.8	8.0	1.0	0.0	10.6	4.2	0.9	7.1	12.9
Rumford Soil, 2% slope											
Average	107.9	3358.6	57.3	37.6	0.4	0.0	9.9	2.1	6.9	13.3	32.2
Minimum	164.5	4485.9	83.6	56.3	1.3	0.0	53.0	5.6	14.0	54.0	79.5
Maximum	9.5	2024.6	34.8	18.7	0.0	0.0	0.0	0.2	3.0	0.0	9.2
st. dev	34.2	532.8	10.3	9.5	0.2	0.0	11.9	1.1	2.2	9.8	14.5
Slagle Soil, 4.5% slope											
Average	131.3	3798.9	64.4	41.7	1.7	0.0	9.5	9.0	3.7	6.1	28.2
Minimum	175.8	4510.6	84.8	60.0	5.0	0.0	55.0	22.7	6.0	38.0	82.1
Maximum	25.7	2703.3	41.7	18.2	0.2	0.0	1.0	1.1	2.0	0.0	6.2
st. dev	27.4	386.9	9.1	10.1	0.9	0.0	11.2	4.4	1.0	5.6	13.2
Uchee Soil, 1% slope											
Average	130.8	3768.1	64.1	42.4	0.2	0.0	10.1	1.6	4.3	6.0	22.0
Minimum	174.7	4510.1	85.1	59.7	0.6	0.0	56.0	4.4	7.0	38.0	65.4
Maximum	19.4	2652.1	41.6	20.6	0.0	0.0	0.0	0.2	2.0	0.0	5.2
st. dev	28.8	402.9	9.1	9.7	0.1	0.0	12.7	0.8	1.0	5.4	12.6
Uchee Soil, 4.5% slope											
Average	129.2	3718.0	63.9	40.8	1.2	0.0	11.0	5.9	15.6	2.6	35.1
Minimum	175.6	4484.1	81.2	59.9	3.6	0.0	57.0	16.0	29.0	23.0	83.0
Maximum	19.0	2617.5	41.6	18.4	0.1	0.0	0.0	0.9	6.0	0.0	13.3
st. dev	28.9	406.7	8.9	10.1	0.6	0.0	13.2	2.9	4.5	2.8	13.7

Table C.3: Crop Yields and Nutrient Losses Before Plan; Corn Rotation With Manure

	Corn Yld (lb./ac)	**Peanut Yld** (lb./ac)	**Wheat Yld** (Bu/ac)	**Soybean Yld** (Bu/ac)	**Erosion** (T/ac)	**Volatil-ization** (lb./ac)	**N03 runoff** (lb./ac)	**Org. N w/sediment** (lb./ac)	**Min. N subsurface flow** (lb./ac)	**Min. N percolate** (lb./ac)	**Total N loss** (lb./ac)
Emporia Soil, 1% slope											
Average	131.6	3811.3	64.1	42.3	0.3	42.7	12.1	4.3	2.6	31.9	50.9
Minimum	171.8	4501.0	85.7	58.5	1.0	138.2	55.0	16.2	5.0	131.0	143.3
Maximum	29.9	2784.6	41.6	20.1	0.0	0.0	1.0	0.3	1.0	1.0	6.3
st. dev	25.2	364.2	9.1	9.4	0.2	60.4	12.5	2.7	1.4	27.5	27.0
Emporia Soil, 4.5% slope											
Average	131.0	3794.4	64.1	41.7	1.6	42.7	12.3	14.1	10.5	23.9	60.7
Minimum	172.3	4502.3	85.7	58.3	4.7	136.0	75.0	53.6	24.0	112.0	149.6
Maximum	28.8	2760.6	41.6	19.1	0.2	0.0	1.0	1.1	3.0	1.0	9.2
st. dev	25.4	367.7	9.1	9.6	0.8	60.5	13.1	9.1	6.5	22.3	26.6
Kinston Soil, 2% slope											
Average	101.6	3660.6	50.5	35.3	0.6	42.8	11.9	13.7	1.9	32.5	60.1
Minimum	162.5	4498.0	74.6	53.3	1.9	136.3	65.0	48.4	4.0	136.0	161.4
Maximum	9.6	2638.2	27.6	17.8	0.1	0.0	1.0	1.3	0.0	0.0	14.1
st. dev	33.4	396.7	10.1	9.4	0.4	60.5	11.7	8.0	1.1	26.8	31.0
Peawick Soil, 1% slope											
Average	96.7	3630.1	43.4	34.2	0.4	42.6	11.7	4.5	1.4	38.2	55.8
Minimum	151.7	4505.1	64.2	49.5	1.1	136.0	79.0	18.5	3.0	144.0	153.3
Maximum	10.2	2681.7	22.5	16.2	0.1	0.0	1.0	0.4	0.0	3.0	12.0
st. dev	30.5	407.0	8.8	7.8	0.2	60.4	12.0	3.1	0.6	28.1	27.7
Peawick Soil, 4.5% slope											
Average	96.2	3609.6	43.4	34.0	1.8	42.7	11.5	14.5	5.5	33.4	64.9
Minimum	151.7	4502.6	64.4	49.6	5.4	135.3	77.0	58.2	11.0	133.0	164.2
Maximum	10.0	2654.8	21.9	16.2	0.2	0.0	1.0	1.2	2.0	3.0	15.2
st. dev	30.7	406.8	8.8	8.0	0.9	60.5	11.9	10.1	2.6	25.4	28.8
Rumford Soil, 2% slope											
Average	107.9	3359.8	57.3	37.6	0.4	42.3	11.6	3.9	12.8	41.6	69.9
Minimum	164.5	4491.2	84.7	56.3	1.2	136.1	56.0	17.6	30.0	139.0	191.7
Maximum	9.5	2024.5	34.8	18.7	0.0	0.0	0.0	0.2	3.0	0.0	9.2
st. dev	34.2	533.5	10.3	9.5	0.2	59.9	12.5	2.8	7.9	32.8	33.6
Slagle Soil, 4.5% slope											
Average	131.3	3800.2	64.6	41.7	1.6	42.7	11.5	14.2	6.2	25.8	57.6
Minimum	175.8	4515.5	85.8	60.0	4.5	135.3	73.0	55.5	13.0	129.0	154.6
Maximum	25.7	2703.3	41.7	18.2	0.2	0.0	1.0	1.2	2.0	0.0	8.2
st. dev	27.5	387.8	9.2	10.1	0.8	60.5	12.3	9.3	3.4	24.9	28.3
Uchee Soil, 1% slope											
Average	130.8	3769.2	64.2	42.4	0.2	42.1	11.7	2.7	7.2	26.8	48.4
Minimum	174.7	4510.1	85.7	59.7	0.6	138.6	66.0	10.4	16.0	127.0	140.1
Maximum	19.4	2652.0	41.6	20.6	0.0	0.0	0.0	0.2	2.0	1.0	9.3
st. dev	28.8	403.6	9.3	9.7	0.1	59.6	13.3	1.7	4.2	23.9	23.4
Uchee Soil, 4.5% slope											
Average	129.3	3718.9	64.2	40.8	1.1	42.4	13.0	9.9	27.7	11.3	61.9
Minimum	175.7	4488.6	85.6	59.9	3.4	136.0	79.0	36.9	64.0	64.0	142.1
Maximum	19.0	2617.5	41.6	18.4	0.1	0.0	1.0	1.0	6.0	0.0	17.2
st. dev	28.9	407.5	9.2	10.1	0.6	60.0	14.2	6.4	16.5	11.8	23.6

Table C.4: Crop Yields and Nutrient Losses Before Plan; Cotton Rotation

	Cotton Yld (lb./ac)	**Peanut Yld** (lb./ac)	**Wheat Yld** (Bu/ac)	**Soybean Yld** (Bu/ac)	**Erosion** (T/ac)	**Volatilization** (lb./ac)	**N03 in runoff** (lb./ac)	**Org. N w/sediment** (lb./ac)	**Min. N subsurface flow** (lb./ac)	**Min. N percolate** (lb./ac)	**Total N loss** (lb./ac)
Emporia Soil, 1% slope											
Average	722.7	3810.7	64.0	42.3	0.4	0.0	10.2	2.7	2.0	11.6	26.5
Minimum	941.8	4500.0	84.8	58.5	1.0	0.0	55.0	7.0	4.0	56.0	71.5
Maximum	392.2	2784.7	41.6	20.1	0.0	0.0	1.0	0.3	1.0	0.0	4.4
st. dev	99.4	363.8	8.9	9.4	0.2	0.0	11.8	1.3	0.8	10.1	13.5
Emporia Soil, 4.5% slope											
Average	717.0	3793.8	64.0	41.7	1.8	0.0	10.3	9.0	7.5	7.9	34.7
Minimum	938.0	4501.2	84.7	58.3	5.3	0.0	54.0	23.6	14.0	51.0	83.9
Maximum	393.2	2760.6	41.6	19.1	0.2	0.0	1.0	1.0	3.0	0.0	8.1
st. dev	98.6	367.3	8.9	9.6	1.0	0.0	11.8	4.5	3.1	7.6	13.9
Kinston Soil, 2% slope											
Average	602.1	3660.2	50.5	35.3	0.7	0.0	9.3	10.8	1.3	12.6	34.0
Minimum	898.0	4498.0	74.6	53.3	2.1	0.0	59.0	28.5	3.0	57.0	90.1
Maximum	273.0	2637.8	27.6	17.8	0.1	0.0	1.0	1.4	0.0	0.0	6.4
st. dev	112.9	396.6	10.1	9.4	0.4	0.0	10.3	5.7	0.5	9.9	15.3
Peawick Soil, 1% slope											
Average	598.3	3629.6	43.4	34.2	0.4	0.0	9.6	2.7	1.0	13.8	27.0
Minimum	836.0	4503.9	64.2	49.5	1.1	0.0	54.0	7.2	1.0	46.0	68.4
Maximum	265.9	2681.8	22.5	16.2	0.1	0.0	1.0	0.3	0.0	1.0	6.9
st. dev	103.1	406.6	8.8	7.8	0.2	0.0	10.7	1.3	0.2	9.3	12.4
Peawick Soil, 4.5% slope											
Average	595.1	3609.1	43.4	34.0	2.1	0.0	9.5	8.6	3.7	11.5	33.3
Minimum	836.7	4501.5	64.4	49.6	5.7	0.0	55.0	23.3	6.0	44.0	80.9
Maximum	264.6	2654.9	21.9	16.2	0.2	0.0	1.0	1.1	2.0	1.0	9.5
st. dev	103.7	406.5	8.8	8.0	1.1	0.0	10.6	4.3	0.9	8.3	13.1
Rumford Soil, 2% slope											
Average	629.8	3359.1	57.2	37.6	0.5	0.0	9.8	2.1	8.7	16.9	37.5
Minimum	894.9	4489.1	83.6	56.3	1.4	0.0	53.0	5.6	17.0	54.0	90.6
Maximum	293.8	2024.6	34.8	18.7	0.0	0.0	0.0	0.2	3.0	0.0	9.2
st. dev	111.3	532.9	10.2	9.5	0.3	0.0	11.8	1.0	3.7	12.1	13.7
Slagle Soil, 4.5% slope											
Average	719.8	3799.5	64.4	41.6	1.9	0.0	9.7	8.9	4.3	8.4	31.4
Minimum	949.0	4514.5	84.8	60.0	5.3	0.0	55.0	22.7	8.0	55.0	82.1
Maximum	381.0	2703.3	41.7	18.2	0.2	0.0	1.0	1.1	2.0	0.0	6.3
st. dev	103.1	387.0	9.0	10.1	1.0	0.0	11.1	4.4	1.4	8.3	13.8
Uchee Soil, 1% slope											
Average	718.6	3770.0	64.1	42.4	0.2	0.0	10.3	1.6	5.4	8.1	25.3
Minimum	948.4	4514.0	85.0	59.7	0.6	0.0	56.0	4.4	10.0	50.0	66.4
Maximum	380.9	2659.3	41.6	20.7	0.0	0.0	1.0	0.2	2.0	0.0	5.2
st. dev	104.8	402.1	9.1	9.7	0.1	0.0	12.5	0.8	2.0	7.7	12.3
Uchee Soil, 4.5% slope											
Average	703.4	3721.5	63.9	40.8	1.3	0.0	11.0	5.8	19.9	2.9	39.6
Minimum	943.0	4484.8	81.1	59.9	3.8	0.0	57.0	16.0	38.0	28.0	83.0
Maximum	382.6	2627.3	41.6	18.5	0.1	0.0	1.0	0.8	6.0	0.0	14.0
st. dev	102.6	405.4	8.9	10.1	0.7	0.0	12.8	2.9	8.1	3.3	13.6

Table C.5: Nutrient Losses Before Plan, Pasture

	Erosion (T/ac)	Volatilization (lb./ac)	N03 in runoff (lb./ac)	Organic N w/sediment (lb./ac)	Mineral N loss w/subsurface flow (lb./ac)	Mineral N loss with percolate (lb./ac)	Total N loss (lb./ac)
CLOVER							
Chickahominy Soil, 1% slope							
Average	0.92	0.00	6.42	7.09	1.15	17.57	32.22
Minimum	3.59	0.00	28.00	23.56	2.00	87.00	118.38
Maximum	0.16	0.00	1.00	1.38	1.00	0.00	6.57
st. dev	0.52	0.00	3.76	3.84	0.35	16.16	19.94
Kinston soil, 2% slope							
Average	1.34	0.00	7.19	19.50	1.49	17.33	45.51
Minimum	5.59	0.00	29.00	70.96	3.00	116.00	190.96
Maximum	0.13	0.00	1.00	2.26	1.00	0.00	4.26
st. dev	0.85	0.00	4.19	11.21	0.51	19.42	29.44
Peawick soil, 1% slope							
Average	0.94	0.00	7.13	6.61	1.00	38.21	52.95
Minimum	3.30	0.00	27.00	20.78	1.00	128.00	153.77
Maximum	0.17	0.00	1.00	1.28	1.00	4.00	11.22
st. dev	0.51	0.00	4.09	3.34	0.00	25.57	28.97
Slagle soil, 4% slope							
Average	2.55	0.00	5.96	14.84	4.63	11.57	37.01
Minimum	10.36	0.00	29.00	50.55	7.00	112.00	171.55
Maximum	0.28	0.00	1.00	1.93	3.00	0.00	9.92
st. dev	1.60	0.00	3.72	8.80	0.66	17.35	23.95
FESCUE							
Chickahominy Soil, 1% slope							
Average	0.19	0.00	8.90	2.42	0.98	22.26	34.55
Minimum	0.81	0.00	30.00	10.18	1.00	67.00	99.58
Maximum	0.05	0.00	3.00	0.57	0.00	1.00	5.99
st. dev	0.12	0.00	4.21	1.60	0.15	14.72	17.45
Kinston soil, 2% slope							
Average	0.28	0.00	11.15	7.04	1.14	32.92	52.25
Minimum	1.34	0.00	34.00	29.06	2.00	108.00	143.70
Maximum	0.06	0.00	3.00	1.70	1.00	4.00	12.84
st. dev	0.20	0.00	4.76	4.51	0.34	18.75	23.67
Peawick soil, 1% slope							
Average	0.21	0.00	8.41	2.36	0.88	33.69	45.34
Minimum	1.00	0.00	29.00	9.95	1.00	78.00	112.01
Maximum	0.04	0.00	3.00	0.50	0.00	5.00	13.78
st. dev	0.14	0.00	4.09	1.50	0.33	15.21	17.41
Slagle soil, 4% slope							
Average	0.53	0.00	8.39	5.12	3.06	28.54	45.11
Minimum	2.52	0.00	30.00	23.06	5.00	104.00	139.87
Maximum	0.10	0.00	2.00	1.17	1.00	2.00	10.53
st. dev	0.39	0.00	4.01	3.63	0.82	19.39	23.56

Table C.6: Crop Yields and Nutrient Losses After Plan; Corn Rotation

	Corn Yld (lb./ac)	Peanut Yld (lb./ac)	Wheat Yld (Bu/ac)	Soybean Yld (Bu/ac)	Erosion (T/ac)	Volatil-ization (lb./ac)	N03 in runoff (lb./ac)	Org. N w/sediment (lb./ac)	Min. N subsurface flow (lb./ac)	Min. N percolate (lb./ac)	Total N loss (lb./ac)
Emporia Soil, 1% slope											
Average	127.1	3787.0	60.6	41.3	0.6	22.3	7.4	4.4	1.0	2.9	15.8
Minimum	161.5	4485.9	72.6	58.2	1.3	44.6	25.0	10.0	2.0	10.0	40.0
Maximum	28.8	2784.0	41.6	20.0	0.1	0.0	1.0	0.8	0.0	0.0	4.2
st. dev	22.8	361.5	6.4	9.6	0.2	17.7	4.3	1.8	0.4	2.1	6.3
Emporia Soil, 4.5% slope											
Average	127.7	3792.1	60.4	41.3	1.7	22.3	4.0	9.0	4.2	3.5	20.7
Minimum	163.2	4491.6	71.9	58.1	4.7	44.6	15.0	24.1	9.0	13.0	49.3
Maximum	27.8	2760.6	41.6	19.1	0.2	0.0	0.0	1.0	1.0	0.0	5.1
st. dev	23.2	366.9	6.3	9.7	0.9	17.7	2.4	4.5	1.5	2.5	7.7
Kinston Soil, 2% slope											
Average	101.2	3659.7	50.3	35.1	0.6	15.5	4.5	10.5	0.9	7.2	23.1
Minimum	161.3	4495.3	72.8	53.3	1.9	29.5	22.0	27.4	2.0	30.0	59.2
Maximum	10.1	2638.3	27.6	17.8	0.1	0.0	0.0	1.4	0.0	0.0	4.4
st. dev	33.0	396.0	9.8	9.5	0.4	11.6	2.7	5.5	0.3	4.8	9.6
Peawick Soil, 1% slope											
Average	96.0	3628.2	43.3	33.9	0.4	21.8	3.9	2.7	0.5	5.6	12.6
Minimum	146.2	4497.5	63.3	49.5	1.1	43.4	13.0	6.8	1.0	21.0	34.4
Maximum	11.2	2681.8	22.4	16.2	0.1	0.0	0.0	0.3	0.0	0.0	4.0
st. dev	29.5	406.3	8.7	7.9	0.2	17.2	2.0	1.3	0.5	3.6	5.1
Peawick Soil, 4.5% slope											
Average	95.4	3607.8	43.4	33.8	2.0	21.8	3.9	8.6	2.2	4.7	19.4
Minimum	146.5	4495.0	63.4	49.6	5.4	43.4	13.0	21.5	4.0	19.0	43.1
Maximum	11.0	2654.9	21.8	16.2	0.2	0.0	0.0	1.1	1.0	0.0	4.6
st. dev	29.6	406.1	8.7	8.1	1.0	17.2	2.1	4.2	0.7	3.1	7.1
Rumford Soil, 2% slope											
Average	103.9	3356.2	52.9	37.3	0.4	23.2	3.8	2.1	4.8	7.0	17.8
Minimum	151.1	4466.5	68.5	56.3	1.2	46.4	14.0	5.9	10.0	32.0	49.5
Maximum	10.2	2024.6	34.7	18.7	0.0	0.1	0.0	0.2	2.0	0.0	4.6
st. dev	30.7	532.8	7.1	9.6	0.2	18.3	2.3	1.1	1.7	5.0	7.1
Slagle Soil, 4.5% slope											
Average	127.9	3795.2	60.6	41.3	1.7	21.3	3.8	9.0	2.4	3.6	18.8
Minimum	166.3	4494.7	72.5	59.8	4.5	42.2	15.0	23.1	5.0	13.0	46.9
Maximum	25.4	2703.4	41.7	18.2	0.2	0.0	0.0	1.1	1.0	0.0	3.2
st. dev	25.1	386.4	6.4	10.2	0.9	16.7	2.3	4.4	1.0	2.8	7.5
Uchee Soil, 1% slope											
Average	127.6	3765.8	61.0	42.0	0.2	23.5	3.7	1.6	3.0	3.2	11.6
Minimum	165.0	4508.1	74.3	59.6	0.6	47.4	14.0	4.6	5.0	13.0	29.0
Maximum	20.3	2652.1	41.6	20.6	0.0	0.0	0.0	0.2	1.0	0.0	3.2
st. dev	26.5	402.4	6.7	9.9	0.1	18.8	2.2	0.8	1.1	2.3	4.4
Uchee Soil, 4.5% slope											
Average	124.8	3715.7	59.5	40.4	1.2	23.5	4.1	6.0	10.6	1.5	22.1
Minimum	161.0	4476.0	70.9	59.8	3.4	47.4	16.0	16.4	22.0	7.0	49.0
Maximum	19.8	2617.5	41.6	18.4	0.1	0.1	0.0	0.9	4.0	0.0	6.0
st. dev	25.9	406.3	5.9	10.2	0.6	18.8	2.5	2.9	4.4	1.3	8.0

Table C.7: Crop Yields and Nutrient Losses After Plan; Cotton Rotation

	Cotton (lb./ac)	**Peanut Yld** (lb./ac)	**Wheat Yld** (Bu/ac)	**Soybean Yld** (Bu/ac)	**Erosion** (T/ac)	**Volatil-ization** (lb./ac)	**N03 in runoff** (lb./ac)	**Org. N w/sediment** (lb./ac)	**Mineral N subsurface flow** (lb./ac)	**Mineral N percolate** (lb./ac)	**Total N loss** (lb./ac)
Emporia Soil, 1% slope											
Average	722.7	3810.1	60.0	42.3	0.4	7.6	4.3	2.7	1.4	6.9	15.3
Minimum	941.8	4499.3	71.6	58.3	1.0	23.5	16.0	7.1	3.0	30.0	45.8
Maximum	392.2	2784.7	41.6	20.1	0.0	0.0	0.0	0.3	0.0	0.0	2.4
st. dev	99.3	363.4	6.2	9.3	0.2	10.0	2.4	1.3	0.6	5.2	6.5
Emporia Soil, 4.5% slope											
Average	716.9	3793.3	59.6	41.6	1.8	7.6	4.4	9.1	5.2	4.7	23.4
Minimum	938.0	4499.2	70.7	58.1	5.3	23.4	17.0	23.8	11.0	24.0	60.6
Maximum	393.2	2760.6	41.6	19.1	0.2	0.0	0.0	1.0	1.0	0.0	5.1
st. dev	98.6	366.9	5.9	9.5	1.0	10.0	2.5	4.5	2.2	3.8	8.7
Kinston Soil, 2% slope											
Average	602.1	3660.0	50.4	35.3	0.7	5.9	4.6	10.8	0.9	8.6	24.8
Minimum	898.0	4497.2	72.8	53.3	2.1	20.0	22.0	28.8	2.0	37.0	72.3
Maximum	273.0	2637.8	27.6	17.8	0.1	0.0	0.0	1.4	0.0	0.0	4.4
st. dev	112.9	396.3	9.8	9.4	0.4	8.0	2.6	5.7	0.4	6.1	10.8
Peawick Soil, 1% slope											
Average	598.3	3629.4	43.3	34.2	0.4	7.4	4.2	2.7	0.7	7.9	15.5
Minimum	836.0	4501.8	63.2	49.5	1.1	23.2	15.0	7.2	1.0	26.0	41.6
Maximum	265.9	2681.8	22.5	16.2	0.1	0.0	0.0	0.3	0.0	0.0	3.5
st. dev	103.1	406.3	8.6	7.8	0.2	9.9	2.2	1.3	0.5	4.9	6.3
Peawick Soil, 4.5% slope											
Average	595.0	3608.9	43.4	34.0	2.1	7.4	4.2	8.7	2.7	6.6	22.3
Minimum	836.7	4499.3	63.3	49.6	5.7	23.2	15.0	23.2	5.0	25.0	56.1
Maximum	264.6	2654.9	21.9	16.2	0.2	0.0	0.0	1.1	1.0	0.0	4.6
st. dev	103.8	406.2	8.7	8.0	1.1	9.9	2.3	4.3	1.0	4.3	8.3
Rumford Soil, 2% slope											
Average	629.7	3358.5	52.2	37.5	0.5	7.9	4.2	2.1	6.0	10.1	22.4
Minimum	894.3	4486.1	67.3	56.3	1.4	24.1	16.0	5.8	13.0	34.0	60.5
Maximum	293.8	2024.6	34.8	18.7	0.0	0.0	0.0	0.2	2.0	0.0	5.2
st. dev	111.3	533.0	6.7	9.5	0.3	10.3	2.3	1.0	2.8	6.6	8.5
Slagle Soil, 4.5% slope											
Average	719.7	3798.9	59.9	41.6	1.8	7.4	4.2	9.0	3.0	4.9	21.2
Minimum	949.0	4512.1	72.0	59.7	5.3	23.1	16.0	22.8	6.0	27.0	57.3
Maximum	381.0	2703.3	41.6	18.2	0.2	0.0	0.0	1.1	1.0	0.0	3.1
st. dev	103.2	386.6	6.0	10.1	1.0	9.8	2.4	4.5	1.3	4.1	8.4
Uchee Soil, 1% slope											
Average	718.6	3769.2	60.4	42.3	0.2	7.8	4.2	1.6	3.8	4.5	14.1
Minimum	948.4	4514.0	73.9	59.6	0.6	23.8	15.0	4.5	7.0	27.0	39.1
Maximum	380.9	2659.3	41.6	20.7	0.0	0.0	0.0	0.2	1.0	0.0	3.2
st. dev	104.8	401.6	6.4	9.7	0.1	10.2	2.3	0.8	1.6	3.7	5.6
Uchee Soil, 4.5% slope											
Average	703.4	3720.9	58.7	40.8	1.3	7.8	4.7	5.9	13.6	1.8	26.0
Minimum	943.0	4481.9	70.1	59.8	3.8	24.0	18.0	16.2	28.0	12.0	57.2
Maximum	382.6	2627.3	41.6	18.5	0.1	0.0	0.0	0.8	4.0	0.0	5.9
st. dev	102.7	405.0	5.5	10.1	0.7	10.3	2.6	2.9	6.4	1.6	9.7

Table C.8: Crop Yields and Nutrient Losses After Plan; Pasture

	Erosion (T/ac)	Volatilization (lb./ac)	N03 in runoff (lb./ac)	Organic N w/sediment (lb./ac)	Mineral N loss w/subsurface flow (lb./ac)	Mineral N loss with percolate (lb./ac)	Total N loss (lb./ac)
CLOVER							
Chickahominy Soil, 1% slope							
Average	0.90	11.67	7.33	7.86	1.45	18.40	35.05
Minimum	3.48	12.98	35.00	27.80	2.00	94.00	136.36
Maximum	0.15	9.12	1.00	1.44	1.00	0.00	6.65
st. dev	0.51	0.52	4.27	4.46	0.50	17.53	22.19
Kinston soil, 2% slope							
Average	1.34	11.60	8.06	20.70	1.73	18.16	48.65
Minimum	5.56	13.03	34.00	78.23	3.00	129.00	214.23
Maximum	0.13	8.88	1.00	2.38	1.00	0.00	4.38
st. dev	0.85	0.55	4.69	12.22	0.52	21.06	32.25
Peawick soil, 1% slope							
Average	0.92	11.75	8.29	7.45	1.00	41.20	57.93
Minimum	3.21	13.05	28.00	25.12	1.00	146.00	176.45
Maximum	0.17	9.23	1.00	1.33	1.00	4.00	11.27
st. dev	0.50	0.56	4.52	3.98	0.00	29.09	33.35
Slagle soil, 4% slope							
Average	2.50	11.72	6.53	16.31	4.90	12.00	39.74
Minimum	10.03	13.83	30.00	59.07	7.00	124.00	196.07
Maximum	0.27	8.56	1.00	2.05	3.00	0.00	10.05
st. dev	1.55	0.63	3.97	10.07	0.72	18.48	26.41
FESCUE							
Chickahominy Soil, 1% slope							
Average	0.18	11.61	9.57	2.67	0.96	21.09	34.29
Minimum	0.78	17.39	31.00	11.60	2.00	66.00	106.80
Maximum	0.05	5.64	3.00	0.58	0.00	1.00	6.99
st. dev	0.12	1.28	4.57	1.84	0.24	14.63	18.62
Kinston soil, 2% slope							
Average	0.28	11.49	11.60	7.47	1.21	31.99	52.27
Minimum	1.34	16.22	36.00	31.77	2.00	111.00	152.79
Maximum	0.06	6.95	3.00	1.81	0.00	4.00	10.85
st. dev	0.20	1.01	5.36	4.94	0.43	18.97	25.44
Peawick soil, 1% slope							
Average	0.20	11.71	8.89	2.64	0.75	33.46	45.75
Minimum	0.96	16.53	34.00	11.63	1.00	92.00	120.63
Maximum	0.04	6.90	2.00	0.52	0.00	5.00	12.03
st. dev	0.13	1.17	4.14	1.76	0.43	16.75	20.29
Slagle soil, 4% slope							
Average	0.52	11.66	8.67	5.63	3.09	27.32	44.71
Minimum	2.42	17.56	32.00	26.27	5.00	106.00	151.65
Maximum	0.09	5.54	2.00	1.20	1.00	2.00	9.14
st. dev	0.37	1.41	4.33	4.15	1.04	20.14	26.05

Table C.9: Partial Budget, Farm 3-Isle of Wight County

Proposed change: Adoption of Nutrient Management Plan

Additional Costs ($)		Additional Income ($)	0
Manure spreading			
labor @ $8/hr	939		
fuel and lubrication	1107		
Manure Slurry Store			
depreciation	4183		
interest	3765		
maintenance	628		
insurance	628		
Pump			
depreciation	563		
interest	135		
maintenance	113		
insurance	23		
Honey Wagon			
depreciation	2000		
interest	480		
maintenance	400		
insurance	80		
Total Additional Costs	15041		
Reduced Income ($)		Reduced Costs ($)	
corn	434	Commercial Nitrogen	8387
172 bu @ $2.52/bu		32256 lb. @$.26/lb.	
wheat	1761	Commercial Phosphorus	4032
591 bu @ $2.98/bu		16128 lb. @$.25/lb.	
Total Reduced Income	2195	Pumping Lagoon	5291
		custom charge	
		Total Reduced Costs	17710
A. Total annual additional costs and reduced income	$ 17236	B. Total annual additional income and reduced costs	$ 17710
			$ 17236
		Net change in profit (B-A)	$ 473

Appendix D: Piedmont Poultry

Soils

Most pasture is modeled on Cecil soil with 4.5 percent and 10.5 percent slopes and Appling soil with a 4.5 percent slope. Pasture used for hay only is modeled only on the Cecil soil. The percentage of a specific soil within a field is estimated using soil maps of the farm.

Weather

The simulations use internally generated weather data which is based on parameters established for Richmond, VA. The weather parameters have been calculated by EPIC model developers..

Crop Rotations

Basically, pasture falls into one of three categories: 1) clover - fescue pasture used for grazing and some hay, 2) clover - fescue used for grazing and stockpiled in the fall, and 3) orchard grass - clover used for hay only. Pasture used for grazing and is grazed rotationally. Each pasture is grazed for 7 or 8 days at a time with a rest period of at least 30 days. Pasture used for grazing is sometimes used for one hay cutting in mid-April. Pasture that is stockpiled (approximately 39 acres) has hay cuttings in mid-April and late June after which grazing does not resume until December. Pasture used for hay only has three cuttings taken in mid-April, late June, and late August.

Although pasture used for hay only is orchard grass - clover, all pasture is modeled as clover-fescue. Unfortunately, EPIC does not contain a crop file for orchard grass. Both fescue and orchard grass are tall-growing cool season grasses with similar stature, rates of development, and nutrient content[38]. Therefore, it was determined that the use of an EPIC developed crop file for fescue to represent orchard grass would be more beneficial in terms of this evaluation than the development of a new file.

Commercial Fertilizer and Manure Applications

The modeling of pasture is identical before and after the nutrient management plan with the exception of the changes in fertilizer application rates and nutrient content of the litter. Pasture stockpiled in fall receives manure applications in late summer or early fall. Remaining pasture receives manure in the spring. The nutrient content of the litter is taken from the test values used in developing the nutrient management plan. These values are shown in Table D.1. while crop yields and nutrient losses (as estimated by EPIC) are included in Tables D.2 -D..

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[38] information received from Dr. Dale Wolf, retired Professor, Department of Crop and Soil Environmental Sciences, VPI&SU.

Partial Budget Analysis

The additional costs resulting from the adoption of new management practices with the implementation of the initial plan are calculated first. These costs include the construction cost of the two storage sheds and composter, the cost of the spreader, the additional time required to clean out the poultry houses, the time required for composting, and the cost of delivering litter to other producers in the area. The original storage shed cost approximately $12,000. Cost share covered $7,500 leaving the farmer with a cost of $4,500. The storage shed is valued over a life of 15 years with an annual depreciation of $300. Using an interest rate of 6 percent, annual interest costs for the shed are $135. Annual maintenance and insurance costs are each calculated as 0.5 percent of the original cost of the shed resulting in total annual cost for the shed of $555. The composter cost $5,000. Cost share covered $3,500 resulting in a cost of $1,500 for the farmer. The composter is also valued over a 15 year life resulting in an annual depreciation of $100. Using an interest rate of 6 percent, annual interest costs for the composter are estimated at $45 annually. Maintenance and insurance costs are again calculated as 0.5 percent of the initial cost resulting in a total annual cost of $195 for the composter. The second litter storage shed was constructed at a cost of 15,500. Once again, cost share covered $7,500 resulting in a farmer cost of $8,000. Valued over a life of 15 years, annual depreciation is $533. Annual interest costs are estimated at $240 using an interest rate of 6 percent. With annual maintenance and insurance costs of $78, the total annual cost for the second shed is $929. The litter spreader is owned jointly with a neighboring farmer and therefore only half the cost is reflected in the partial budget. The initial cost of $5,500 was split by the two farmers. Therefore, valued over a ten year life, the annual depreciation is $275. Using an interest rate of 6 percent, annual interest costs are approximately $83 while maintenance costs for each farmer are estimated at $75 annually. Insurance cost is calculated as 0.5 percent of the initial cost resulting in a total annual cost of $447. Due to changes in handling practices of litter, it takes approximately 5 hours longer to clean out each poultry house. Therefore, the cost of fuel and time associated with cleaning out the poultry houses must be calculated. The five poultry houses are cleaned out once a year, resulting in an additional 25 hours of labor. Valuing labor at $8 per hour results in an additional cost of $200. A 65 hp tractor with a front end loader is used to clean out the houses. Diesel fuel is valued at $1.05 per gallon. The amount of fuel used in gallons per hour is calculated using the of data found from tractor tests at the University of Nebraska.[39] Lubrication and filters are calculated at fifteen percent of fuel costs.[2] This results in a total cost of $86 for fuel and lubrication.

With the construction of the storage sheds and the decrease in application rates of litter to pasture, the farmer is able to sell excess litter to other area producers. The cost of time for delivering and fuel must be calculated. With the implementation of the nutrient management plan, the application of poultry litter was reduced to 3 tons per acre. Litter is delivered to area producers using a 14 foot dump truck. It takes approximately 45 minutes to load and deliver 7 tons of litter. Therefore it would take approximately 40 hours to load and deliver all excess litter. Valuing labor at $8 per hour results in a cost of $320. Delivering 374 tons of litter hauling 7 tons at a time would take 54 trips. Valuing fuel at $1.05 per gallon results in an annual cost of for fuel of $91.

One additional cost must also be included in the budget. The cost of the time required to compost must be calculated. The farmer estimates that composting takes approximately 10 minutes per day resulting in an additional labor requirement of approximately 61 hours annually. Valuing labor at $8 per hour results in an additional cost of $487.

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[39] Ronald D. Kay. *Farm Management: Planning, Control, and Implementation.* Second Edition. McGraw-Hill, Inc., US, 1986. p312.

With the reduction of poultry litter application to pasture, hay yields do decrease. Therefore, the reduction in income must also be calculated. With a reduction in poultry litter application from 4 tons per acre to 3 tons per acre, hay yields do decrease by 0.3 tons per acre resulting in an overall reduction of 9.36 tons per acre. Valued at $60 per ton, this results in a decreased income of approximately $562.

With the construction of the litter storage facilities, the farmer is able to store excess litter until it is sold to other producers in the area. In this manner, the farmer has an additional income that must also be calculated. Each year, approximately 750 tons of litter is produced. 40 tons is used on the farm for feed. At an application rate of 3 tons per acre , approximately 374 tons of excess litter is available for sale annually. Valued at $20 per ton, this results in an increase in income of $7,480.

With the construction of the composter, it is no longer necessary for the farmer to incinerate poultry carcasses. Using the results of an evaluation of disposal systems by Crews, Blake, and Donald, the cost per hundredweight of carcass disposal by means of incineration is valued at $8.92. Using a mortality rate of 3 percent and average carcass weight of 2 pounds, the total annual cost of incineration is $3,639.

Table D.1: Manure Nutrient Content, Farm 4

Manure Type	TKN	NH_4	P_20_5	percent MOISTURE
Litter (before plan)	54.6	8.09	61.1	25.17
Litter (after plan)	59.01	11.4	80.38	15.4

Table D.2: Nitrogen Losses Before Plan; Pasture used for Grazing and Hay

	Pasture Yield (T/ac)	**Erosion** (T/ac)	**Volatil -ization** (lb./ac)	**NO3 in runoff** (lb./ac)	**Org. N w/sediment** (lb./ac)	**Mineral N subsurface flow** (lb./ac)	**Mineral N percolate** (lb./ac)	**Total N loss** (lb./ac)
Cecil Soil; 4.5 percent slope								
average	1.1	0.3	20.1	0.4	9.1	1.1	7.4	18.0
minimum	0.6	0.0	17.0	0.0	0.0	0.0	0.0	0.0
maximum	1.6	5.4	21.5	3.6	155.0	2.7	63.4	172.0
st.dev	0.2	0.7	0.7	0.6	19.4	0.5	8.9	24.1
Cecil Soil; 10.5 percent slope								
average	1.1	2.2	20.1	0.7	41.1	2.4	6.3	50.5
minimum	0.6	0.0	17.4	0.0	0.0	0.9	0.0	0.9
maximum	1.6	29.2	21.6	4.5	467.8	5.4	54.5	479.4
st.dev	0.2	3.7	0.7	0.8	63.1	1.0	7.7	66.0
Appling Soil; 4.5 percent slope								
average	1.3	0.3	21.5	0.4	8.1	1.0	4.6	14.1
minimum	0.6	0.0	18.5	0.0	0.0	0.0	0.0	0.0
maximum	1.7	4.7	22.9	3.6	139.9	2.7	48.2	146.2
st.dev	0.3	0.6	0.7	0.6	17.5	0.4	6.6	20.6

Table D.3: Nitrogen Losses Before Plan; Pasture Stockpiled in Fall

	Pasture Yield (T/ac)	Erosion (T/ac)	Volatil -ization (lb./ac)	NO3 in runoff (lb./ac)	Org. N w/sediment (lb./ac)	Mineral N subsurface flow (lb./ac)	Mineral N percolate (lb./ac)	Total N loss (lb./ac)
Cecil Soil; 4.5 percent slope								
average	2.3	0.3	19.4	0.7	7.5	1.4	10.1	19.6
minimum	1.4	0.0	13.7	0.0	0.0	0.9	0.9	1.8
maximum	3.4	3.7	22.2	6.2	111.5	3.6	33.0	124.9
st.dev	0.5	0.4	1.2	1.0	12.1	0.5	6.5	16.3
Cecil Soil; 10.5 percent slope								
average	2.3	2.0	19.3	1.0	35.0	3.1	7.3	46.2
minimum	1.4	0.0	13.1	0.0	0.0	0.9	0.0	3.0
maximum	3.4	20.7	21.8	7.1	358.8	7.1	27.7	371.3
st.dev	0.5	2.5	1.2	1.2	41.9	0.9	5.1	44.4
Appling Soil; 4.5 percent slope								
average	2.4	0.2	20.7	0.7	6.8	1.3	10.1	18.9
minimum	1.4	0.0	15.1	0.0	0.0	0.9	0.9	1.8
maximum	3.6	3.1	23.3	5.4	98.7	2.7	27.7	112.1
st.dev	0.4	0.4	1.1	1.0	10.9	0.5	6.0	15.0

Table D.4: Nitrogen Losses Before Plan; Pasture used for Hay only

	Pasture Yield (T/ac)	Erosion (T/ac)	Volatil -ization (lb./ac)	NO3 in runoff (lb./ac)	Org. N w/sediment (lb./ac)	Mineral N subsurface flow (lb./ac)	Mineral N percolate (lb./ac)	Total N loss (lb./ac)
Cecil Soil; 4.5 percent slope								
average	3.4	0.2	20.1	0.5	6.3	0.4	0.2	7.4
minimum	1.8	0.0	17.0	0.0	0.0	0.0	0.0	0.0
maximum	5.6	4.1	21.5	2.7	111.3	0.9	9.8	115.8
st.dev	0.7	0.7	0.7	0.6	19.1	0.5	5.5	23.3
Cecil Soil; 10.5 percent slope								
average	3.4	1.6	20.0	0.6	27.9	0.4	0.2	29.1
minimum	1.8	0.0	17.4	0.0	0.0	0.0	0.0	0.0
maximum	5.6	22.2	21.6	3.6	351.2	1.8	8.0	355.7
st.dev	0.7	3.2	0.7	0.7	49.5	0.5	0.8	50.2

Table D.5: Nitrogen Losses After Plan; Pasture used Grazing and Hay

	Pasture Yield (T/ac)	Erosion (T/ac)	Volatil -ization (lb./ac)	NO3 in runoff (lb./ac)	Org. N w/sediment (lb./ac)	Mineral N subsurface flow (lb./ac)	Mineral N percolate (lb./ac)	Total N loss (lb./ac)
Cecil Soil; 4.5 percent slope								
average	1.1	0.3	9.5	0.4	7.5	0.8	4.4	13.1
minimum	0.6	0.0	8.1	0.0	0.0	0.0	0.0	0.0
maximum	1.6	5.5	10.2	3.6	125.9	1.8	48.2	131.3
st.dev	0.2	0.7	0.4	0.6	15.7	0.4	6.2	18.4
Cecil Soil; 10.5 percent slope								
average	1.1	2.3	9.5	0.6	33.8	1.6	3.8	39.8
minimum	0.6	0.0	8.2	0.0	0.0	0.9	0.0	0.9
maximum	1.6	29.4	10.3	3.6	380.6	4.5	42.0	386.9
st.dev	0.2	3.8	0.3	0.7	51.4	0.8	5.6	53.2
Appling Soil; 4.5 percent slope								
average	1.2	0.3	10.2	0.4	6.5	0.7	2.8	10.4
minimum	0.6	0.0	8.8	0.0	0.0	0.0	0.0	0.0
maximum	1.7	4.8	10.8	2.7	113.3	2.7	30.4	118.6
st.dev	0.2	0.6	0.3	0.6	14.0	0.5	4.2	15.9

Table D.6: Nitrogen Losses After Plan; Pasture Stockpiled in Fall

	Pasture Yield (T/ac)	Erosion (T/ac)	Volatil -ization (lb./ac)	NO3 in runoff (lb./ac)	Org. N w/sediment (lb./ac)	Mineral N subsurface flow (lb./ac)	Mineral N percolate (lb./ac)	Total N loss (lb./ac)
Cecil Soil; 4.5 percent slope								
average	2.2	0.2	9.2	0.6	5.8	0.9	6.8	14.2
minimum	1.3	0.0	6.5	0.0	0.0	0.0	0.0	0.0
maximum	3.3	3.6	10.5	3.6	86.5	2.7	22.3	95.4
st.dev	0.4	0.4	0.5	0.7	9.5	0.3	4.3	11.8
Cecil Soil; 10.5 percent slope								
average	2.2	2.1	9.2	0.8	29.2	1.9	5.1	37.1
minimum	1.3	0.0	6.2	0.0	0.0	0.9	0.0	2.0
maximum	3.3	21.5	10.3	4.5	292.6	6.2	18.7	300.6
st.dev	0.4	2.6	0.5	0.8	34.5	0.7	3.6	35.9
Appling Soil; 4.5 percent slope								
average	2.2	0.2	9.8	0.7	5.5	0.8	6.4	13.4
minimum	1.4	0.0	7.2	0.0	0.0	0.0	0.9	0.9
maximum	3.4	3.3	11.1	3.6	79.7	1.8	17.9	87.8
st.dev	0.4	0.4	0.5	0.7	8.9	0.3	3.8	11.1

Table D.7: Nitrogen Losses After Plan; Pasture used for Hay only

	Pasture Yield (T/ac)	Erosion (T/ac)	Volatil -ization (lb./ac)	NO3 in runoff (lb./ac)	Org. N w/sediment (lb./ac)	Mineral N subsurface flow (lb./ac)	Mineral N percolate (lb./ac)	Total N loss (lb./ac)
Cecil Soil; 4.5 percent slope								
average	3.10	0.25	9.51	0.46	5.40	0.54	0.08	6.48
minimum	1.70	0.00	8.07	0.00	0.00	0.00	0.00	0.00
maximum	5.05	4.30	10.19	2.68	90.44	0.89	3.57	94.90
st.dev	0.62	0.59	0.35	0.57	11.83	0.44	0.39	12.33
Cecil Soil; 10.5 percent slope								
average	3.07	1.81	9.49	0.58	23.99	0.55	0.04	25.16
minimum	1.66	0.00	8.23	0.00	0.00	0.00	0.00	0.00
maximum	5.09	22.94	10.23	2.68	283.67	0.89	3.57	286.35
st.dev	0.63	3.44	0.33	0.66	40.84	0.43	0.31	41.33

Table D.8: Partial Budget, Farm 4

Proposed change: Adoption of updated nutrient management plan in comparison to before plan

Additional Costs ($)		Additional Income ($)	
original shed		Sell excess poultry litter	
depreciation	300	374 tons @ $20/ Ton	7480
interest	135		
maintenance	60		
insurance	60		
composter			
depreciation	100		
interest	45		
maintenance	25		
insurance	25		
second shed			
depreciation	533		
interest	240		
maintenance	78		
insurance	78		
Spreader			
depreciation	275		
interest	83		
maintenance	75		
insurance	14		
Cleaning out houses			
labor @ $8/hr.	200		
fuel and lubrication	86		
Delivering litter			
labor @ $8/hr	321		
fuel	91		
Composting			
labor @ $8/hr	487		
Total Additional Costs	3308		
Reduced Income ($)		Reduced Costs ($)	
hay		Incineration	
9.36 tons @ $60/ton	562	408 cwt. @ 8.92	3639
A. Total annual additional costs and reduced income	$ 3870	B. Total annual additional income and reduced costs	$ 11119
			$ 3870
		Net change in profit (B-A)	$ 7249

Appendix E: Linear Programming Model for Farm 2

```
$OFFSYMLIST OFFSYMXREF
SETS
R crop rotation - management - soil combinations
/BEFCRFB,BEFCRFC,BEFCRN,BEFCBXFB,BEFCBXFC,BEFCBXN
BEFCRCBFB,BEFCRCBFC,BEFCRCBN,BEFCBAFB,BEFCBAFC,BEFCBAN
AFTCWCFB,AFTCWCFC,AFTCWCN,AFTCBSFB,AFTCBSFC,AFTCBSN
AFTCBAFB,AFTCBAFC,AFTCBAN
RYECBSFB,RYECBSFC,RYECBSN,RYECBAFB,RYECBAFC,RYECBAN
FALLCWCFB,FALLCWCFC,FALLCWCN,FALLCBSFB
FALLCBSFC,FALLCBSN,FALLCBAFB,FALLCBAFC,FALLCBAN
CWC9FB,CWC9FC,CWC9N,CBS9FB,CBS9FC,CBS9N
CBA9FB,CBA9FC,CBA9N,CWC12FB,CWC12FC,CWC12N
CBS12FB,CBS12FC,CBS12N,CBA12FB,CBA12FC,CBA12N
CWC3FB,CWC3FC,CWC3N,CBS3FB,CBS3FC,CBS3N,
CBA3FB,CBA3FC,CBA3N,NOMANCWCFB,NOMANCWCFC,NOMANCWCN
NOMANCBSFB,NOMANCBSFC,NOMANCBSN,NOMANCBAFB
NOMANCBAFC,NOMANCBAN,HIGHNCWCFB,HIGHNCWCFC
HIGHNCWCN,HIGHNCBSFB,HIGHNCBSFC,HIGHNCBSN
HIGHNCBAFB,HIGHNCBAFC,HIGHNCBAN,SPLTNCWCFB,SPLTNCWCFC
SPLTNCWCN,SPLTNCBSFB,SPLTNCBSFC,SPLTNCBSN
SPLTNCBAFB,SPLTNCBAFC,SPLTNCBAN,PLT30CWCFB
PLT30CWCFC,PLT30CWCN,PLT30CBSFB,PLT30CBSFC
PLT30CBSN,PLT30CBAFB,PLT30CBAFC,PLT30CBAN
AUTOCWCFB,AUTOCWCFC,AUTOCWCN,AUTOCBSFB,AUTOCBSFC
AUTOCBSN,AUTOCBAFB,AUTOCBAFC,AUTOCBAN
IDLECROPFB,IDLECROPFC,IDLECROPN
BEFPASTB,BEFPASTC,BEFPASTD,BEFPASTE,AFTPASTB
AFTPASTC,AFTPASTD,AFTPASTE,COMMPASTB,COMMPASTC
COMMPASTD,COMMPASTE,MANPASTB,MANPASTC,MANPASTD,MANPASTE
IDLEPASTB,IDLEPASTC,IDLEPASTD,IDLEPASTE/

A accounting activities
/CORNSIL,BARLEYSIL,WHEATSIL,SOYBEANBU,ALFALFAHAY
SUDEXHAY,OMILKCOWS,DRYCOWS,HEIFFERS,COMMNAPP,MANNAPP,PLANTAVN
TOTNITVOL,TOTNITRUN,TOTNITSED,TOTNITSSF,TOTNITPER
TOTPHOSRUN,TOTPHOSSED,TOTNITLOSS,TOTPHOSLOS,EROSION
LIQMANURE,SSMANURE/

E sell excess crops
/SELLCSIL,SELLBARLWH,SELLALF,SELLSOY,SELLSUDEX,SELLMILK/

B purchase additional feed
/BUYCGRAIN,BUYSOY,BUYALF,BUYBARLGR,BUYLITTER,BUYDISTGR/

C crop production transfer
/CORN,BARLEY,WHEAT,SOYBEAN,ALFALFA,SUDEX/
```

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S soils
/CROPFREDB,,CROPFREDC,CROPTIMB,CROPNIXA
PASTFREDB,PASTFREDC,PASTFREDD,PASTFREDE/

P manure production
/LIQMANPROD,SSMANPROD/

M manure use
/CROPMANURE,PASTMANURE/

T plant available nitrogen application transfer
/COMMNFERT,MANNFERT,TOTALNFERT/

N nutrient loss transfer
/NITVOL,NITRUN,NITSED,NITSSFLOW,NITLEACH,PRUNOFF
PSED,SOILEROS,NITROGEN,PHOSPHORUS/

F feed rations
/CSILUSE,ALFUSE,CGRAINUSE,BGRAINUSE,SOYBEANUSE,DGRAINUSE
BWSILUSE,LITTERUSE,SUDEXUSE/

G grazed pasture
/PASTURE/

K milk cows
/MILKCOWS/

O other livestock
/DRYCOWS,HEIFFER/

D milk production
/MILK/

L n loss restriction
/RESTRICT/;

PARAMETERS
C1(R) average annual production cost of rotation
/BEFCRFB -263.79,BEFCRFC -263.79, BEFCRN -263.79
BEFCBXFB -296.98, BEFCBXFC -296.98, BEFCBXN -296.98
BEFCRCBFB -309.62, BEFCRCBFC -309.62,BEFCRCBN -309.62
BEFCBAFB -247.57,BEFCBAFC -247.57,BEFCBAN -247.57
AFTCWCFB -188.62, AFTCWCFC -188.62,AFTCWCN -188.62
AFTCBSFB -202.69,AFTCBSFC -202.69,AFTCBSN -202.69
AFTCBAFB -215.53,AFTCBAFC -215.53,AFTCBAN -215.53
RYECBSFB -216.46,RYECBSFC -216.46,RYECBSN -216.46
RYECBAFB -221.43,RYECBAFC -221.43, RYECBAN -221.43
FALLCWCFB -188.62, FALLCWCFC -188.62, FALLCWCN -188.62
FALLCBSFB -202.69,FALLCBSFC -202.69,FALLCBSN -202.69
FALLCBAFB -215.53, FALLCBAFC -215.53, FALLCBAN -215.53
CWC9FB -187.24, CWC9FC -187.24, CWC9N -187.24
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CBS9FB -201.3, CBS9FC -201.3, CBS9N -201.3
CBA9FB -214.51, CBA9FC -214.51, CBA9N -214.51
CWC12FB -196.71, CWC12FC -196.71, CWC12N -196.71
CBS12FB -208.06,CBS12FC -208.06,CBS12N -208.06
CBA12FB -218.31, CBA12FC -218.31, CBA12N -218.31
CWC3FB -193.28, CWC3FC -193.28, CWC3N -193.28
CBS3FB -204.83, CBS3FC -204.83, CBS3N -204.83
CBA3FB -216.91, CBA3FC -216.91, CBA3N -216.91
NOMANCWCFB -205.62, NOMANCWCFC -205.62, NOMANCWCN -205.62
NOMANCBSFB -219.68, NOMANCBSFC -219.68, NOMANCBSN -219.68
NOMANCBAFB -224.11, NOMANCBAFC -224.11, NOMANCBAN -224.11
HIGHNCWCFB -209.69, HIGHNCWCFC -209.69, HIGHNCWCN -209.69
HIGHNCBSFB -223.76, HIGHNCBSFC -223.76, HIGHNCBSN -223.76
HIGHNCBAFB -225.85, HIGHNCBAFC -225.85, HIGHNCBAN -225.85
SPLTNCWCFB -210.63, SPLTNCWCFC -210.63, SPLTNCWCN -210.63
SPLTNCBSFB -224.7, SPLTNCBSFC -224.7, SPLTNCBSN -224.7
SPLTNCBAFB -226.29, SPLTNCBAFC -226.29, SPLTNCBAN -226.29
PLT30CWCFB -210.63, PLT30CWCFC -210.63, PLT30CWCN -210.63
PLT30CBSFB -224.7, PLT30CBSFC -224.7, PLT30CBSN -224.7
PLT30CBAFB -226.29, PLT30CBAFC -226.29, PLT30CBAN -226.29
AUTOCWCFB -213.41, AUTOCWCFC -213.19, AUTOCWCN -206.17
AUTOCBSFB -225.91, AUTOCBSFC -229.05, AUTOCBSN -224.38
AUTOCBAFB -229.05, AUTOCBAFC -229.42, AUTOCBAN -227.42
BEFPASTB -218.34, BEFPASTC -218.34
BEFPASTD -218.34, BEFPASTE -218.34
AFTPASTB -78, AFTPASTC -78
AFTPASTD -78, AFTPASTE -78
COMMPASTB -60.44,COMMPASTC -60.44
COMMPASTD -60.44,COMMPASTE -60.44
MANPASTB -121.47, MANPASTC -121.47
MANPASTD -121.47,MANPASTE -121.47/
C2(a) cost of dairy cows excluding feeds
/OMILKCOWS -1193.31/
C3(E) sell crops not needed to meet feed requirements
/SELLCSIL 25
 SELLBARLWH 19
 SELLALF 50
 SELLSOY 240
 SELLSUDEX 70
 SELLMILK 13/
C4(B) purchase additional feed requirements
/BUYCGRAIN -175
 BUYSOY -266
 BUYALF -110
 BUYBARLGR -117
 BUYLITTER -15
 BUYDISTGR -190/
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SOIL(S) maximum soil amount in acres
/CROPFREDB 92.4
  0
 CROPFREDC 145.2
 CROPNIXA 26.4
 PASTFREDB 5
 PASTFREDC 20
 PASTFREDD 5
 PASTFREDE 20/
LIVE(K) maximum number of dairy cows
/MILKCOWS 160/;

TABLE T1(C,R) annual crop production within each rotation
         BEFCRFB BEFCRFC BEFCRN  BEFCBXFB BEFCBXFC
CORN       19.3    19.2     11.4    9.55    9.45
BARLEY                              5.1     5.1
SUDEX                               3.00    2.95

+          BEFCBXN BEFCRCBFB BEFCRCBFC BEFCRCBN
CORN         6.15    18.9      18.8      12.1
BARLEY       4.10     5.1       5.05      4.05
SUDEX        1.9

+         BEFCBAFB BEFCBAFC BEFCBAN
CORN         5.6      5.543   3.486
BARLEY       2.914    2.914   2.257
ALFALFA      1.93     1.886   1.414
SUDEX        1.114    1.05    0.771

  +     AFTCWCFB AFTCWCFC AFTCWCN AFTCBSFB AFTCBSFC
CORN       9        8.8      6.15       9.45   9.4
BARLEY                                  5.1    5.05
WHEAT      5.1      5.1      3.6
SOYBEAN                                20.45  19.9

 +        AFTCBSN AFTCBAFB AFTCBAFC AFTCBAN
CORN        6.15    5.429   5.371     3.457
BARLEY      3.9     2.886   2.886     2.2
SOYBEAN    13.55    8.871   8.764     5.571
ALFALFA             1.97    1.929     1.414

+          RYECBSFB RYECBSFC RYECBSN
CORN          9.4     9.3      6.15
BARLEY       5.05    5.05       3.9
SOYBEAN      20.5    19.95     13.55

+           RYECBAFB RYECBAFC RYECBAN
CORN          5.4     5.371    3.486
BARLEY        2.886   2.886    2.2
SOYBEAN       8.871   8.764    5.571
ALFALFA       1.97    1.929    1.414
```

+	FALLCWCFB	FALLCWCFC	FALLCWCN
CORN	8.95	8.75	6
WHEAT	5.1	5.1	3.6

+	FALLCBSFB	FALLCBSFC	FALLCBSN
CORN	9.45	9.35	5.95
BARLEY	5.05	5.05	3.9
SOYBEAN	20.45	19.85	13.55

+	FALLCBAFB	FALLCBAFC	FALLCBAN
CORN	5.429	5.371	3.371
BARLEY	2.886	2.886	2.2
SOYBEAN	8.871	8.764	5.571
ALFALFA	1.97	1.929	1.414

+	CWC9FB	CWC9FC	CWC9N
CORN	8.95	8.75	6.15
WHEAT	5.05	5.05	3.35

+	CBS9FB	CBS9FC	CBS9N
CORN	9.45	9.35	6.1
BARLEY	5.05	5.05	3.65
SOYBEAN	20.05	19.55	13.55

+	CBA9FB	CBA9FC	CBA9N
CORN	5.429	5.371	3.457
BARLEY	2.886	2.857	2.029
SOYBEAN	8.807	8.7	5.571
ALFALFA	1.886	1.843	1.371

+	CWC12FB	CWC12FC	CWC12N
CORN	9.05	8.85	6.2
WHEAT	5.1	5.1	3.65

+	CBS12FB	CBS12FC	CBS12N
CORN	9.5	9.4	6.15
BARLEY	5.1	5.05	3.9
SOYBEAN	21.1	20.55	13.6

+	CBA12FB	CBA12FC	CBA12N
CORN	5.429	5.371	3.457
BARLEY	2.886	2.886	2.2
SOYBEAN	8.893	8.807	5.571
ALFALFA	1.886	1.843	1.371

+	CWC3FB	CWC3FC	CWC3N
CORN	9	8.8	6.15
WHEAT	5.1	5.1	3.85

+	CBS3FB	CBS3FC	CBS3N
CORN	9.5	9.4	6.15
BARLEY	5.05	5.05	4.05
SOYBEAN	20.35	19.8	13.55

+	CBA3FB	CBA3FC	CBA3N
CORN	5.4	5.371	3.457
BARLEY	2.886	2.886	2.314
SOYBEAN	8.893	8.786	5.571
ALFALFA	1.929	1.886	1.414

+	NOMANCWCFB	NOMANCWCFC	NOMANCWCN
CORN	9	8.8	6.15
WHEAT	5.1	5.1	3.85

+	NOMANCBSFB	NOMANCBSFC	NOMANCBSN
CORN	9.5	9.4	6.1
BARLEY	5.1	5.05	4.05
SOYBEAN	20.1	19.6	13.5

+	NOMANCBAFB	NOMANCBAFC	NOMANCBAN
CORN	5.4	5.343	3.457
BARLEY	2.886	2.886	2.314
SOYBEAN	8.893	8.786	5.571
ALFALFA	1.886	1.843	1.414

+	HIGHNCWCFB	HIGHNCWCFC	HIGHNCWCN
CORN	9.05	8.85	6.2
WHEAT	5.1	5.1	3.85

+	HIGHNCBSFB	HIGHNCBSFC	HIGHNCBSN
CORN	9.55	9.45	6.15
BARLEY	5.1	5.05	4.05
SOYBEAN	20.4	19.85	13.5

+	HIGHNCBAFB	HIGHNCBAFC	HIGHNCBAN
CORN	5.4	5.343	3.457
BARLEY	2.886	2.886	2.314
SOYBEAN	8.936	8.829	5.571
ALFALFA	1.886	1.843	1.414

+	SPLTNCWCFB	SPLTNCWCFC	SPLTNCWCN
CORN	9	8.8	6.2
WHEAT	5.1	5.1	3.85

```
+          SPLTNCBSFB SPLTNCBSFC SPLTNCBSN
CORN         9.5         9.4        6.2
BARLEY       5.1         5.05       4.05
SOYBEAN     20.1        19.6       13.5

+           SPLTNCBAFB SPLTNCBAFC SPLTNCBAN
CORN            5.4      5.343      3.486
BARLEY          2.886    2.886      2.314
SOYBEAN         8.893    8.807      5.571
ALFALFA         1.886    1.843      1.414

+          PLT30CWCFB PLT30CWCFC PLT30CWCN
CORN         9              8.8      6.2
WHEAT        5.1            5.1      3.85

+          PLT30CBSFB PLT30CBSFC PLT30CBSN
CORN           9.5       9.45      6.2
BARLEY         5.1       5.05      4.05
SOYBEAN       20.1      19.65     13.5

+          PLT30CBAFB PLT30CBAFC PLT30CBAN
CORN           5.4      5.343       3.486
BARLEY         2.886    2.886       2.314
SOYBEAN        8.893    8.807       5.571
ALFALFA        1.886    1.843       1.414

+          AUTOCWCFB AUTOCWCFC AUTOCWCN
CORN         9.05      8.85      6.2
WHEAT        5.1       5.1       3.95

+         AUTOCBSFB AUTOCBSFC AUTOCBSN
CORN         9.5       9.4       6.2
BARLEY       5.05      5.05      4.1
SOYBEAN     19.9      19.1      13.55

+         AUTOCBAFB AUTOCBAFC AUTOCBAN
CORN          5.457    5.429   3.571
BARLEY        2.886    2.886   2.314
SOYBEAN       8.871    8.807   5.571
ALFALFA       1.886    1.843   1.414 ;

TABLE T2(C,A) crop production transfer
         CORNSIL BARLEYSIL WHEATSIL SOYBEANBU ALFALFAHAY SUDEXHAY
CORN      -1
BARLEY             -1
WHEAT                          -1
SOYBEAN                                 -1
ALFALFA                                           -1
SUDEX                                                       -1;
```

```
TABLE T3(S,R) soil restriction
           BEFCRFB BEFCRFC BEFCRN  BEFCBXFB BEFCBXFC
CROPFREDB     1                         1

CROPFREDC             1                         1
CROPNIXA                     1

+          BEFCBXN BEFCRCBFB BEFCRCBFC BEFCRCBN
CROPFREDB              1

CROPFREDC                        1
CROPNIXA      1                            1

+           BEFCBAFB BEFCBAFC BEFCBAN
CROPFREDB       1
CROPFREDC               1
CROPNIXA                         1

  +       AFTCWCFB AFTCWCFC AFTCWCN AFTCBSFB AFTCBSFC
CROPFREDB   1                           1

CROPFREDC           1                            1
CROPNIXA                     1

 +         AFTCBSN AFTCBAFB AFTCBAFC AFTCBAN
CROPFREDB              1

CROPFREDC                       1
CROPNIXA      1                         1

+           RYECBSFB RYECBSFC RYECBSN RYECBAFB RYECBAFC
CROPFREDB     1                            1

CROPFREDC              1                           1
CROPNIXA                         1
+           RYECBAN FALLCWCFB FALLCWCFC FALLCWCN
CROPFREDB              1

CROPFREDC                         1
CROPNIXA     1                              1

+            FALLCBSFB FALLCBSFC FALLCBSN FALLCBAFB
CROPFREDB       1                           1

CROPFREDC                 1
CROPNIXA                            1
+           FALLCBAFC FALLCBAN  CWC9FB CWC9FC CWC9N
CROPFREDB                           1

CROPFREDC     1                            1
CROPNIXA                 1                       1
```

```
+             CBS9FB CBS9FC CBS9N CBA9FB CBA9FC CBA9N
CROPFREDB       1                    1

CROPFREDC              1                   1
CROPNIXA                      1                    1

+             CWC12FB CWC12FC CWC12N CBS12FB CBS12FC
CROPFREDB        1                      1

CROPFREDC                1                       1
CROPNIXA                        1

+              CBS12N CBA12FB CBA12FC CBA12N CWC3FB
CROPFREDB                1                      1

CROPFREDC                        1
CROPNIXA         1                       1

+               CWC3FC CWC3N CBS3FB CBS3FC CBS3N
CROPFREDB                      1

CROPFREDC         1                    1
CROPNIXA                 1                    1

+              CBA3FB CBA3FC CBA3N NOMANCWCFB NOMANCWCFC
CROPFREDB         1                     1

CROPFREDC              1                          1
CROPNIXA                       1

+               NOMANCWCN NOMANCBSFB NOMANCBSFC NOMANCBSN
CROPFREDB                      1

CROPFREDC                                1
CROPNIXA           1                                 1
+               NOMANCBAFB NOMANCBAFC NOMANCBAN HIGHNCWCFB
CROPFREDB           1                                1

CROPFREDC                     1
CROPNIXA                                   1

+               HIGHNCWCFC HIGHNCWCN HIGHNCBSFB HIGHNCBSFC
CROPFREDB                                1

CROPFREDC           1                                1
CROPNIXA                       1
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```
+               HIGHNCBSN HIGHNCBAFB HIGHNCBAFC HIGHNCBAN
CROPFREDB                    1

CROPFREDC                              1
CROPNIXA            1                                1

+              SPLTNCWCFB SPLTNCWCFC SPLTNCWCN SPLTNCBSFB
CROPFREDB            1                              1

CROPFREDC                     1
CROPNIXA                                 1

+              SPLTNCBSFC SPLTNCBSN SPLTNCBAFB SPLTNCBAFC
CROPFREDB                              1

CROPFREDC          1                                1
CROPNIXA                      1

+              SPLTNCBAN PLT30CWCFB PLT30CWCFC PLT30CWCN
CROPFREDB                     1

CROPFREDC                                1
CROPNIXA           1                                1
+              PLT30CBSFB PLT30CBSFC PLT30CBSN PLT30CBAFB
CROPFREDB         1                                1

CROPFREDC                     1
CROPNIXA                                 1

+              PLT30CBAFC PLT30CBAN AUTOCWCFB AUTOCWCFC
CROPFREDB                               1

CROPFREDC           1                              1
CROPNIXA                    1

+               AUTOCWCN AUTOCBSFB AUTOCBSFC AUTOCBSN
CROPFREDB                    1

CROPFREDC                             1
CROPNIXA            1                           1

+                AUTOCBAFB AUTOCBAFC AUTOCBAN
CROPFREDB            1

CROPFREDC                      1
CROPNIXA                                1

+                 IDLECROPFB IDLECROPFC IDLECROPN
CROPFREDB             1
CROPFREDC                         1
CROPNIXA                                    1
```

```
+            BEFPASTB BEFPASTC BEFPASTD
PASTFREDB       1
PASTFREDC                  1
PASTFREDD                           1
PASTFREDE

+         BEFPASTE AFTPASTB AFTPASTC AFTPASTD AFTPASTE COMMPASTB
PASTFREDB            1                                    1
PASTFREDC                      1
PASTFREDD                                1
PASTFREDE   1                                     1

+         COMMPASTC COMMPASTD COMMPASTE MANPASTB MANPASTC
PASTFREDB                                  1
PASTFREDC    1                                      1
PASTFREDD             1
PASTFREDE                       1

+           MANPASTD MANPASTE IDLEPASTB
PASTFREDB                         1
PASTFREDC
PASTFREDD      1
PASTFREDE               1

+           IDLEPASTC IDLEPASTD IDLEPASTE
PASTFREDC       1
PASTFREDD                 1
PASTFREDE                          1;

TABLE T4(P,A) manure production based on number of dairy cows
             OMILKCOWS LIQMANURE SSMANURE
LIQMANPROD     7.25625     -1
SSMANPROD      1.5625                -1;

TABLE T5(M,R) annual manure use per rotation
           BEFCRFB BEFCRFC BEFCRN  BEFCBXFB BEFCBXFC
CROPMANURE                             6       6
PASTMANURE
+          BEFCBXN BEFCRCBFB BEFCRCBFC BEFCRCBN
CROPMANURE   6
PASTMANURE
+          AFTCWCFB AFTCWCFC AFTCWCN AFTCBSFB AFTCBSFC
CROPMANURE      6          6    6         6        6
PASTMANURE
 +            AFTCBSN AFTCBAFB AFTCBAFC AFTCBAN
CROPMANURE        6     6         3        3
PASTMANURE
```

```
+            RYECBSFB RYECBSFC RYECBSN RYECBAFB RYECBAFC RYECBAN
CROPMANURE     6       6        6        3        3       3

+             FALLCWCFB FALLCWCFC FALLCWCN FALLCBSFB
CROPMANURE      6         6         6        6

+            FALLCBSFC FALLCBSN FALLCBAFB FALLCBAFC FALLCBAN
CROPMANURE   6         6            3         3       3

+            CWC9FB CWC9FC CWC9N
CROPMANURE     9       9     9

+            CBS9FB CBS9FC CBS9N   CBA9FB CBA9FC CBA9N
CROPMANURE     9      9      9      4.5     4.5    4.5

+             CWC12FB CWC12FC CWC12N
CROPMANURE      12      12     12

+           CBS12FB CBS12FC CBS12N  CBA12FB CBA12FC CBA12N
CROPMANURE  12         12    12         6       6      6

+              CWC3FB CWC3FC CWC3N
CROPMANURE      3      3     3

+            CBS3FB CBS3FC CBS3N CBA3FB CBA3FC CBA3N
CROPMANURE     3      3      3     1.5    1.5    1.5

+             BEFPASTB
CROPMANURE
PASTMANURE      28
+           BEFPASTC BEFPASTD BEFPASTE AFTPASTB AFTPASTC AFTPASTD
CROPMANURE
PASTMANURE     28     28        28       5         5       5
+           AFTPASTE COMMPASTB COMMPASTC COMMPASTD COMMPASTE
CROPMANURE
PASTMANURE      5
+            MANPASTB MANPASTC MANPASTD MANPASTE
CROPMANURE
PASTMANURE      13      13        13      13   ;

TABLE T6(M,A) manure use transfer for restriction
             LIQMANURE SSMANURE
CROPMANURE      -1
PASTMANURE                -1   ;

TABLE T7(T,R) annual plant available nitrogen applications
           BEFCRFB BEFCRFC BEFCRN BEFCBXFB BEFCBXFC BEFCBXN
COMMNFERT    190    190      190     175      175     175
MANNFERT                              61       61      61
```

```
+            BEFCRCBFB BEFCRCBFC BEFCRCBN
COMMNFERT      225        225       225

+             BEFCBAFB BEFCBAFC BEFCBAN
COMMNFERT        94.29   94.29    94.29

+            AFTCWCFB AFTCWCFC AFTCWCN
COMMNFERT      45        45      45
MANNFERT       65        65      65

+            AFTCBSFB AFTCBSFC AFTCBSN AFTCBAFB AFTCBAFC AFTCBAN
COMMNFERT      55       55       55      31.43     31.43   31.43
MANNFERT       65       65       65      32.14     32.14   32.14

+             RYECBSFB RYECBSFC RYECBSN
COMMNFERT      55         55      55
MANNFERT       65         65      65

+              FALLCWCFB FALLCWCFC FALLCWCN
COMMNFERT          45        45      45
MANNFERT           65        65      65

+              FALLCBSFB FALLCBSFC FALLCBSN
COMMNFERT          55       55        55
MANNFERT           65       65        65

+               FALLCBAFB FALLCBAFC FALLCBAN
COMMNFERT          31.43     31.43   31.43
MANNFERT           32.14     32.14   32.14

+              CWC9FB CWC9FC CWC9N
COMMNFERT        2.5    2.5   2.5
MANNFERT        97.5   97.5  97.5

+              CBS9FB CBS9FC CBS9N  CBA9FB CBA9FC CBA9N
COMMNFERT        12.5  12.5   12.5    9.64  9.64   9.64
MANNFERT         97.5  97.5   97.5   48.21 48.21  48.21

+              CWC12FB CWC12FC CWC12N
MANNFERT         130     130     130

+              CBS12FB CBS12FC CBS12N CBA12FB CBA12FC CBA12N
COMMNFERT                                 4.29   4.29    4.29
MANNFERT        130      130     130    64.29  64.29   64.29

+               CWC3FB CWC3FC CWC3N
COMMNFERT        77.5   77.5  77.5
MANNFERT         32.5   32.5  32.5
```

```
+              CBS3FB   CBS3FC CBS3N CBA3FB CBA3FC CBA3N
COMMNFERT       87.5     87.5   87.5   47.5  47.5   47.5
MANNFERT        32.5     32.5   32.5   16.07 16.07  16.17

+              NOMANCWCFB NOMANCWCFC NOMANCWCN
COMMNFERT          110        110         110

+              NOMANCBSFB NOMANCBSFC NOMANCBSN
COMMNFERT         120      120            120

+              NOMANCBAFB NOMANCBAFC NOMANCBAN
COMMNFERT        63.57        63.57     63.57

+              HIGHNCWCFB HIGHNCWCFC HIGHNCWCN
COMMNFERT         125        125      125

+              HIGHNCBSFB HIGHNCBSFC HIGHNCBSN
COMMNFERT        135         135       135

+             HIGHNCBAFB HIGHNCBAFC HIGHNCBAN
COMMNFERT       70          70         70

+               SPLTNCWCFB SPLTNCWCFC SPLTNCWCN
COMMNFERT          110        110         110

+               SPLTNCBSFB SPLTNCBSFC SPLTNCBSN
COMMNFERT          120        120         120

+              SPLTNCBAFB SPLTNCBAFC SPLTNCBAN
COMMNFERT         63.57     63.57      63.57

+               PLT30CWCFB PLT30CWCFC PLT30CWCN
COMMNFERT         110        110         110

+                 PLT30CBSFB PLT30CBSFC PLT30CBSN
COMMNFERT            120      120            120

+              PLT30CBAFB PLT30CBAFC PLT30CBAN
COMMNFERT        63.57        63.57     63.57

+                AUTOCWCFB AUTOCWCFC AUTOCWCN
COMMNFERT          103       102.5

+            AUTOCBSFB AUTOCBSFC AUTOCBSN
COMMNFERT       115        109      98.5

+             AUTOCBAFB AUTOCBAFC AUTOCBAN
COMMNFERT        58.86      59.71    55.14

+             BEFPASTB   BEFPASTC BEFPASTD BEFPASTE
MANNFERT         141       141       141      141
```

```
+             AFTPASTB AFTPASTC AFTPASTD AFTPASTE
COMMNFERT       40        40       40        40
MANNFERT        25        25       25        25

+             COMMPASTB COMMPASTC COMMPASTD COMMPASTE
COMMNFERT        65        65          65        65

 +             MANPASTB MANPASTC MANPASTD MANPASTE
MANNFERT            65      65         65       65;

TABLE T8(T,A) nitrogen application transfer
              COMMNAPP MANNAPP PLANTAVN
COMMNFERT        -1
MANNFERT                 -1
TOTALNFERT        1       1        -1      ;


TABLE T9(N,R) average annual nutrient loss
           BEFCRFB BEFCRFC BEFCRN  BEFCBXFB BEFCBXFC
NITVOL       11       11     10.5    28.1       28.1
NITRUN        3.3      6      5       3.4        5.0
NITSED       13.9     45      5.5    23.5       82.9
NITSSFLOW     3.7      7.7    8       3.9        7.8
NITLEACH      3.7      2     84.4    15.9        7.8
PRUNOFF                 .1     .6
PSED          7.3     28.8    2.3     5.8       22.3
SOILEROS      1.9     12.3     .2     1.8       11.1
NITROGEN
PHOSPHORUS

+          BEFCBXN BEFCRCBFB BEFCRCBFC  BEFCRCBN
NITVOL       26.5    13         13         12.3
NITRUN        5.2     3.7        5.4        5.1
NITSED        7.9    13.6       49.6        5.2
NITSSFLOW     7.6     3.5        7.3        7.8
NITLEACH     90.5     3.4        1.8       74.5
PRUNOFF       0.3                            .2
PSED          1.9     4.4       17.3        1.5
SOILEROS      0.2     2.2       13           .2
NITROGEN
PHOSPHORUS

+           BEFCBAFB BEFCBAFC BEFCBAN
NITVOL          5.2     5.2       5
NITRUN          3.2     4.1       3.4
NITSED          6.1    22         2.5
NITSSFLOW       2.2     4.6       4.2
NITLEACH        4.1     2        49.8
PRUNOFF                  .1        .5
PSED            3.2    12.4        .9
SOILEROS        0.9     5.5        .1
```

+	AFTCWCFB	AFTCWCFC	AFTCWCN	AFTCBSFB	AFTCBSFC
NITVOL	36.5	36.4	34.2	37	37.1
NITRUN	2.3	3.2	4	3.1	4.4
NITSED	11.1	40	4	14.8	55.6
NITSSFLOW	2.4	5	4.5	2.6	5.4
NITLEACH	2.8	1.4	48.4	3.5	1.9
PRUNOFF			.2		
PSED	3.7	14.3	1.2	4	15.8
SOILEROS	1.3	7.6	.1	1.5	9.3

+	AFTCBSN	AFTCBAFB	AFTCBAFC	AFTCBAN
NITVOL	34.7	18.6	18.6	17.5
NITRUN	4.5	3.5	4.5	3.5
NITSED	5.4	8.3	30	3.1
NITSSFLOW	5.3	2.2	4.4	3.7
NITLEACH	63.2	2.9	1.5	48.1
PRUNOFF	.2		.1	.4
PSED	1.4	2.5	10	.9
SOILEROS	.1	.9	5.3	.1

+	RYECBSFB	RYECBSFC	RYECBSN
NITVOL	37	37.1	34.7
NITRUN	3.2	4.5	4.4
NITSED	15.9	58	5.6
NITSSFLOW	2.4	4.9	5
NITLEACH	2.6	1.4	56.3
PRUNOFF			.2
PSED	4.3	16.6	1.5
SOILEROS	1.6	9.9	.1

+	RYECBAFB	RYECBAFC	RYECBAN
NITVOL	18.6	18.6	17.5
NITRUN	3.6	4.6	3.5
NITSED	8.6	31.2	3.1
NITSSFLOW	2.1	4.2	3.6
NITLEACH	2.4	1.2	44.9
PRUNOFF		.1	.4
PSED	2.6	10.3	.9
SOILEROS	.9	5.4	.1

+	FALLCWCFB	FALLCWCFC	FALLCWCN
NITVOL	36.2	36.2	34.3
NITRUN	2.4	3.3	3.7
NITSED	10.9	39.4	4
NITSSFLOW	2.4	5	4.6
NITLEACH	2.8	1.4	52.7
PRUNOFF			.2
PSED	3.7	13.9	1.2
SOILEROS	1.2	7.3	.1

+	FALLCBSFB	FALLCBSFC	FALLCBSN
NITVOL	36.8	36.8	34.8
NITRUN	3.4	4.6	4.4
NITSED	15.6	57.5	5.7
NITSSFLOW	3	6.2	5.6
NITLEACH	4.1	2.2	70.5
PRUNOFF			.2
PSED	4.3	16.7	1.5
SOILEROS	1.5	8.9	.1

+	FALLCBAFB	FALLCBAFC	FALLCBAN
NITVOL	18.5	18.5	17.5
NITRUN	3.6	4.6	3.5
NITSED	8.6	30.8	3.2
NITSSFLOW	2.3	4.8	3.9
NITLEACH	3.1	1.6	51.3
PRUNOFF		.1	.4
PSED	2.7	10.4	.9
SOILEROS	.8	5.1	.1

+	CWC9FB	CWC9FC	CWC9N
NITVOL	52	51.9	49
NITRUN	1.8	2.3	3.2
NITSED	12.5	45.4	4.5
NITSSFLOW	2	4.1	3.7
NITLEACH	2.2	1.1	41.4
PRUNOFF			.3
PSED	4.2	16.1	1.3
SOILEROS	1.2	7.2	.1

+	CBS9FB	CBS9FC	CBS9N	CBA9FB	CBA9FC	CBA9N
NITVOL	52.6	52.6	49.6	26.4	26.3	24.9
NITRUN	2.6	3.5	3.8	3.1	4	3.1
NITSED	17.5	65	6.2	9.6	34.5	3.4
NITSSFLOW	2.3	4.6	4.5	1.9	3.9	3.2
NITLEACH	3	1.6	56.6	2.4	1.3	43.8
PRUNOFF			.3		.1	.4
PSED	5.1	19.9	1.7	3	11.7	1
SOILEROS	1.5	8.9	.1	.8	5.1	.1

+	CWC12FB	CWC12FC	CWC12N
NITVOL	69.1	69	65.2
NITRUN	2.1	2.8	3.7
NITSED	14	50.8	4.9
NITSSFLOW	2.7	5.5	4.6
NITLEACH	4.2	2	55.5
PRUNOFF			.4
PSED	4.6	17.7	1.4
SOILEROS	1.2	7.1	.1

+	CBS12FB	CBS12FC	CBS12N	CBA12FB	CBA12FC	CBA12N
NITVOL	69.1	69.1	65.2	34.6	34.6	32.8
NITRUN	2.9	3.8	4.1	3.3	4.1	3.2
NITSED	19.7	72.6	6.7	10.5	37.7	3.7
NITSSFLOW	2.7	5.4	5.0	2.2	4.3	3.5
NITLEACH	3.9	2.1	65.0	3.1	1.6	48.4
PRUNOFF			.4		.1	.5
PSED	5.8	22.6	1.8	3.3	12.8	1.1
SOILEROS	1.5	8.7	.1	.8	5	.1

+	CWC3FB	CWC3FC	CWC3N
NITVOL	21.5	21.4	20.2
NITRUN	2.5	3.4	4.2
NITSED	9.8	35.4	3.7
NITSSFLOW	2.2	4.5	4.4
NITLEACH	2.3	1.3	41.7
PRUNOFF			.2
PSED	3.8	14.7	1.2
SOILEROS	1.3	7.8	.1

+	CBS3FB	CBS3FC	CBS3N	CBA3FB	CBA3FC	CBA3N
NITVOL	22	22	20.7	11.2	11.2	10.5
NITRUN	3.3	4.6	4.7	3.6	4.7	3.6
NITSED	13.1	49.5	5	7.6	27.5	2.9
NITSSFLOW	2.4	4.9	5.1	2	4.1	3.6
NITLEACH	3	1.7	55.3	2.8	1.4	43.6
PRUNOFF			.2		.1	.4
PSED	4	15.9	1.4	2.5	10	.9
SOILEROS	1.6	9.6	.1	.9	5.4	.1

+	NOMANCWCFB	NOMANCWCFC	NOMANCWCN
NITVOL	6.4	6.4	6.1
NITRUN	2.5	3.5	4.2
NITSED	8.5	30.5	3.3
NITSSFLOW	2.2	4.6	4.5
NITLEACH	2.3	1.2	42.8
PRUNOFF			.4
PSED	5	18.8	1.3
SOILEROS	1.4	8.2	.1

+	NOMANCBSFB	NOMANCBSFC	NOMANCBSN
NITVOL	7	7	6.7
NITRUN	3.3	4.8	4.7
NITSED	11.4	43.2	4.6
NITSSFLOW	2.4	5	5.2
NITLEACH	3	1.6	56
PRUNOFF			.5
PSED	5.4	21.1	1.6
SOILEROS	1.7	10	.1

+	NOMANCBAFB	NOMANCBAFC	NOMANCBAN
NITVOL	3.7	3.7	3.5
NITRUN	3.6	4.7	3.6
NITSED	6.9	25	2.7
NITSSFLOW	2	4.1	3.7
NITLEACH	3	1.5	44.1
PRUNOFF		.1	.5
PSED	3.3	12.8	1
SOILEROS	.9	5.6	.1

+	HIGHNCWCFB	HIGHNCWCFC	HIGHNCWCN
NITVOL	7.3	7.3	6.9
NITRUN	2.6	3.7	4.4
NITSED	8.6	30.7	3.3
NITSSFLOW	2.6	5.4	5.1
NITLEACH	3.1	1.6	51.2
PRUNOFF			.4
PSED	5	18.9	1.3
SOILEROS	1.4	8.2	.1

+	HIGHNCBSFB	HIGHNCBSFC	HIGHNCBSN
NITVOL	7.9	7.9	7.5
NITRUN	3.5	5.1	4.9
NITSED	11.5	43.3	4.6
NITSSFLOW	2.7	5.5	5.8
NITLEACH	4	2	64
PRUNOFF			.5
PSED	5.4	21.1	1.6
SOILEROS	1.7	10	.1

+	HIGHNCBAFB	HIGHNCBAFC	HIGHNCBAN
NITVOL	4.1	4.1	3.9
NITRUN	3.7	4.8	3.7
NITSED	6.9	25	2.7
NITSSFLOW	2.1	4.4	3.9
NITLEACH	4.5	2.3	47.7
PRUNOFF		.1	.5
PSED	3.3	12.8	1
SOILEROS	.9	5.6	.1

+	SPLTNCWCFB	SPLTNCWCFC	SPLTNCWCN
NITVOL	6.4	6.4	6.1
NITRUN	2.5	3.5	4.1
NITSED	8.5	30.5	3.3
NITSSFLOW	2.1	4.4	4.1
NITLEACH	2.3	1.2	41.8
PRUNOFF			.4
PSED	5	18.8	1.3
SOILEROS	1.4	8.2	.1

+	SPLTNCBSFB	SPLTNCBSFC	SPLTNCBSN
NITVOL	7	6.9	6.6
NITRUN	3.3	4.6	4.5
NITSED	11.4	43.2	4.6
NITSSFLOW	2.1	4.4	4.5
NITLEACH	3	1.7	54.1
PRUNOFF			.5
PSED	5.4	21.1	1.6
SOILEROS	1.7	10	.1

+	SPLTNCBAFB	SPLTNCBAFC	SPLTNCBAN
NITVOL	3.7	3.7	3.5
NITRUN	3.6	4.6	3.5
NITSED	6.9	25	2.7
NITSSFLOW	1.9	3.9	3.3
NITLEACH	3.1	1.6	43.3
PRUNOFF		.1	.5
PSED	3.3	12.8	1
SOILEROS	.9	5.6	.1

+	PLT30CWCFB	PLT30CWCFC	PLT30CWCN
NITVOL	6.4	6.4	6.1
NITRUN	2.5	3.5	4
NITSED	8.5	30.5	3.3
NITSSFLOW	2	4.2	3.9
NITLEACH	2.3	1.2	40.7
PRUNOFF			.4
PSED	5	18.9	1.3
SOILEROS	1.4	8.2	.1

+	PLT30CBSFB	PLT30CBSFC	PLT30CBSN
NITVOL	6.9	6.9	6.6
NITRUN	3.2	4.4	4.4
NITSED	11.4	43.2	4.6
NITSSFLOW	2	4.2	4.3
NITLEACH	3	1.7	52.3
PRUNOFF			.5
PSED	5.4	21.1	1.6
SOILEROS	1.7	10	.1

+	PLT30CBAFB	PLT30CBAFC	PLT30CBAN
NITVOL	3.7	3.7	3.5
NITRUN	3.6	4.5	3.4
NITSED	6.9	25	2.7
NITSSFLOW	1.9	3.8	3.2
NITLEACH	3.2	1.6	42.6
PRUNOFF		.1	.5
PSED	3.3	12.8	1
SOILEROS	.9	5.6	.1

+	AUTOCWCFB	AUTOCWCFC	AUTOCWCN
NITVOL	5.9	5.9	4.7
NITRUN	1.4	1.9	2.2
NITSED	8.4	30.3	3.3
NITSSFLOW	.9	1.9	1.7
NITLEACH	.9	.5	18.4
PRUNOFF			.4
PSED	4.9	18.7	1.3
SOILEROS	1.4	8.1	.1

+	AUTOCBSFB	AUTOCBSFC	AUTOCBSN
NITVOL	6.6	6.2	5.4
NITRUN	2	2.5	2.7
NITSED	11.4	43.1	4.6
NITSSFLOW	1.3	2.5	2.6
NITLEACH	1.7	.9	33.7
PRUNOFF			.5
PSED	5.4	20.8	1.6
SOILEROS	1.7	10	.1

+	AUTOCBAFB	AUTOCBAFC	AUTOCBAN
NITVOL	3.4	3.4	3
NITRUN	2.8	3.5	2.6
NITSED	6.9	24.9	2.7
NITSSFLOW	1.4	2.9	2.3
NITLEACH	1.6	.9	32.6
PRUNOFF		.1	.5
PSED	3.3	12.8	1
SOILEROS	.9	5.5	.1

+	IDLECROPFB	IDLECROPFC	IDLECROPN	BEFPASTB
NITVOL				38.5
NITRUN	0.9	1.2	1.5	1.5
NITSED	2.5	9.8	2.3	39.7
NITSSFLOW	2.3	4.9	2.9	2.0
NITLEACH	6	3.9	41.4	25.2
PRUNOFF				1.3
PSED	0.7	2.9	0.5	8.5
SOILEROS	0.1	0.6		.7

+	BEFPASTC	BEFPASTD	BEFPASTE	AFTPASTB	AFTPASTC	AFTPASTD
NITVOL	38.5	38.5	38.5	9.6	9.6	9.6
NITRUN	1.5	1.5	1.7	1.1	1.2	1.3
NITSED	103.2	170.7	288.7	11.3	30.2	54.2
NITSSFLOW	4.0	5.3	6.8	1.5	3.2	4.3
NITLEACH	20.6	15.7	7.5	9.8	7.6	5.5
PRUNOFF	1.4	1.3	.8			
PSED	24.0	45.0	96.5	3.4	9.9	19.7
SOILEROS	3.3	8.9	33.3	.7	3.3	9.5

```
+          AFTPASTE COMMPASTB COMMPASTC COMMPASTD COMMPASTE
NITVOL       9.6      4.5        4.5        4.5      4.5
NITRUN       1.4      1.2        1.2        1.4      1.6
NITSED     116.7      6.1       17.1       33.5     87.6
NITSSFLOW    5.5      1.9        3.9        5.2      7.9
NITLEACH     3.1     12.8       10.5        8.6      5.8
PRUNOFF
PSED        51.6      3.7       11.5       24.2     61.5
SOILEROS    38.2       .9        4.3        12.1    44.9
NITROGEN
PHOSPHORUS

+          MANPASTB MANPASTC MANPASTD MANPASTE
NITVOL        17.7     17.7     17.7     17.8
NITRUN         0.9       .8       .8       .9
NITSED        22.3     57.8     98.3    197.4
NITSSFLOW       .5      1.2      1.5      1.7
NITLEACH       3.2      2.1      1.4     1
PRUNOFF         .1       .1       .1
PSED           5.5     15.9     31.3     81.3
SOILEROS      .8        3.7     10.4     48.7
NITROGEN
PHOSPHORUS

+            IDLEPASTB IDLEPASTC IDLEPASTD IDLEPASTE
NITRUN          .8        1         1.2       1.4
NITSED         1.5         5.7      11.9      25.6
NITSSFLOW      1.1         2.3       3.4       4.7
NITLEACH       3.5         2.4       1.7       0.9
PSED           0.6         2.6       5.8      14.1
SOILEROS       0.1         0.6       2.0       7.8;

TABLE T10(N,A) nutrient loss transfer
           TOTNITVOL TOTNITRUN TOTNITSED TOTNITSSF
NITVOL        -1
NITRUN                  -1
NITSED                            -1
NITSSFLOW                                   -1
NITROGEN                 1         1         1

+          TOTNITPER TOTPHOSRUN TOTPHOSSED TOTNITLOSS TOTPHOSLOS
NITLEACH      -1
PRUNOFF                   -1
PSED                                -1
SOILEROS
NITROGEN       1                                -1
PHOSPHORUS                 1           1                    -1

+          EROSION
SOILEROS      -1;
```

```
TABLE T11(F,A) feed ration restriction
            CORNSIL BARLEYSIL WHEATSIL SOYBEANBU ALFALFAHAY
SUDEXHAY
CSILUSE       1
ALFUSE                                                 1
SOYBEANUSE                                  .03
BWSILUSE               1          1
SUDEXUSE                                                        1

+            OMILKCOWS DRYCOWS  HEIFFERS
CSILUSE      -7.625
ALFUSE       -1.9825
CGRAINUSE    -1.4335             -.3431
BGRAINUSE     -.4575             -.3203
SOYBEANUSE    -.61
DGRAINUSE     -.6863
BWSILUSE               -2.184   -3.5999
LITTERUSE                        -.3508;


TABLE T12(F,E) feed ration restriction
           SELLCSIL  SELLBARLWH  SELLALF SELLSOY SELLSUDEX
CSILUSE       -1
ALFUSE                             -1
SOYBEANUSE                                 -1
BWSILUSE                -1
SUDEXUSE                                          -1   ;

TABLE T13(F,B) feed ration restriction
          BUYCGRAIN  BUYSOY BUYALF  BUYBARLGR  BUYLITTER
ALFUSE                        1
CGRAINUSE     1
BGRAINUSE                             1
SOYBEANUSE              1
LITTERUSE                                        1

+            BUYDISTGR
DGRAINUSE         1      ;

TABLE T14(G,R) grazed pasture restriction
        BEFPASTB BEFPASTC BEFPASTD BEFPASTE
PASTURE     1        1        1      1

+       AFTPASTB AFTPASTC AFTPASTD AFTPASTE
PASTURE    1        1       1       1

+       COMMPASTB COMMPASTC COMMPASTD COMMPASTE
PASTURE     1         1        1        1
```

```
+        MANPASTB MANPASTC MANPASTD MANPASTE
PASTURE      1       1        1      1;

TABLE T15(G,A) grazed pasture restriction
         OMILKCOWS
PASTURE    -.3125;

TABLE T16(K,A) number of milk cows
           OMILKCOWS
MILKCOWS       1 ;

TABLE T17(O,A) numbers of other livestock
           OMILKCOWS DRYCOWS HEIFFERS
DRYCOWS       -.25      1
HEIFFER       -.53              1;

TABLE T18(D,A) milk production in thousands of pounds
           OMILKCOWS
MILK           193  ;

TABLE T19(D,E) milk transfer
          SELLMILK
MILK        -1;

TABLE T20(L,A)
           TOTNITLOSS
RESTRICT      1;

SCALAR NITROGEN /100000/;

VARIABLES
Z
X1(R) amount of land in alternative rotations
X2(A) total crop production and nutrient losses
X3(E) excess crops
X4(B) additional feed requirements;
POSITIVE VARIABLE
X1
X2
X3
X4;
```

```
EQUATIONS
PROFITS objective function
CROPS(C) crop production transfers
SOILSC(S)  soil type constraints
MPROD(P)   manure production transfer
MUSE(M) manure use constraint
APP(T) nitrogen application transfer
NUT(N) nutrient loss transfer
FEED(F) feed ration constraint
PAST(G) grazed pasture constraint
MCOWS(K) number of milk cows
OCOWS(O) number of other dry cows and heiffers
MILKPROD(D) milk production transfer
LOSS(L) nutrient loss restriction;

PROFITS..  Z=E=SUM(R,C1(R)*X1(R))+SUM(A,C2(A)*X2(A))+
SUM(E,C3(E)*X3(E))+SUM(B,C4(B)*X4(B));
CROPS(C)..    SUM(R,T1(C,R)*X1(R))+SUM(A,T2(C,A)*X2(A))=E=0;
SOILSC(S)..   SUM(R,T3(S,R)*X1(R))=E=SOIL(S);
MPROD(P).. SUM(A,T4(P,A)*X2(A))=E=0;
MUSE(M)..   SUM(R,T5(M,R)*X1(R))+SUM(A,T6(M,A)*X2(A))=E=0;
APP(T)..SUM(R,T7(T,R)*X1(R))+SUM(A,T8(T,A)*X2(A))=E=0;
NUT(N)..   SUM(R,T9(N,R)*X1(R))+SUM(A,T10(N,A)*X2(A))=E=0;
FEED(F).. SUM(A,T11(F,A)*X2(A))+SUM(E,T12(F,E)*X3(E))+
SUM(B,T13(F,B)*X4(B))=G=0;
PAST(G)..  SUM(R,T14(G,R)*X1(R))+SUM(A,T15(G,A)*X2(A))=E=0;
MCOWS(K)..  SUM(A,T16(K,A)*X2(A))=L=LIVE(K);
OCOWS(O).. SUM(A,T17(O,A)*X2(A))=E=0;
MILKPROD(D).. SUM(A,T18(D,A)*X2(A))+SUM(E,T19(D,E)*X3(E))=E=0;
LOSS(L).. SUM(A,T20(L,A)*X2(A))=L=NITROGEN;
MODEL FARM2 /ALL/;
```

Appendix F: EPIC simulation results for Farm 2 linear programming model

Table F.1: Definitions of Alternative Management Practices

No.	Name	Definition
(1)	BEFCBX	Corn, barley, sudex rotation before adoption of nutrient management
(1)	BEFCRCB	Corn, rye cover, corn, barley rotation before nutrient management
(1)	BEFCBA	Corn, barley, alfalfa rotation before nutrient management
(1)	BEFCR	Corn, rye cover before nutrient management
(2)	AFTCBS	Corn, barley, soybean rotation after nutrient management (current practices)
(2)	AFTCBA	Corn, barley, alfalfa after nutrient management (current practices)
(2)	AFTCWC	Corn, wheat, clover cover rotation with current management practices
(3)	HIGHNCBS	Corn, barley, soybean rotation with higher application of nitrogen to corn than current practices (commercial nitrogen only)
(3)	HIGHNCBA	Corn, barley, alfalfa with high commercial nitrogen application to corn
(3)	HIGHNCWC	Corn, wheat, clover with high commercial nitrogen application to corn
(4)	RYECBS	Corn, barley, soybean rotation with rye cover after soybean harvest
(4)	RYECBA	Corn, barley, soybean rotation with rye cover after soybean harvest
(5)	FALLCBS	Corn, barley, soybean with manure applied to corn the fall prior to planting
(5)	FALLCBA	Corn, barley, alfalfa with manure applied to corn the fall prior to planting
(5)	FALLCWC	Corn, wheat, clover with manure applied to corn the fall prior to planting
(6)	CBS9	Corn, barley, soybean with 9,000 gallons manure applied to corn and barley
(6)	CBA9	Corn, barley, alfalfa with 9,000 gallons manure applied to corn and barley
(6)	CWC9	Corn, wheat, clover with 9,000 gallons manure applied to corn and wheat
(7)	CBS12	Corn, barley, soybean with 12,000 gallons manure applied to corn and barley
(7)	CBA12	Corn, barley, alfalfa with 12,000 gallons manure applied to corn and barley
(7)	CWC12	Corn, wheat, clover with 12,000 gallons manure applied to corn and wheat
(8)	CBS3	Corn, barley, soybean with 3,000 gallons manure applied to corn and barley
(8)	CBA3	Corn, barley, alfalfa with 3,000 gallons manure applied to corn and barley
(8)	CWC3	Corn, wheat, clover with 3,000 gallons manure applied to corn and wheat
(9)	NOMANCBS	Corn, barley, soybean rotation with no manure application
(9)	NOMANCBA	Corn, barley, alfalfa rotation with no manure application
(9)	NOMANCWC	Corn, wheat, clover cover rotation with no manure application
(10)	SPLTNCBS	Corn, barley, soybean rotation with split commercial nitrogen, no manure
(10)	SPLTNCBA	Corn, barley, alfalfa rotation with split commercial nitrogen, no manure
(10)	SPLTNCWC	Corn, wheat, clover cover rotation with split commercial nitrogen, no manure
(11)	PLT30CBS	Corn, barley, soybean rotation with 30 lb. nitrogen applied to corn at planting
(11)	PLT30CBA	Corn, barley, alfalfa rotation with 30 lb. nitrogen applied to corn at planting
(11)	PLT30CWC	Corn, wheat, clover rotation with 30 lb. nitrogen applied to corn at planting
(12)	AUTOCBS	Corn, barley, soybean rotation with fertilizer applied by EPIC as needed
(12)	AUTOCBA	Corn, barley, alfalfa rotation with fertilizer applied by EPIC as needed
(12)	AUTOCWC	Corn, wheat, clover cover rotation with fertilizer applied by EPIC as needed
(13)	IDLECROP	Idle cropland, planted to a fescue - clover cover
(1)	BEFPAST	Pasture before nutrient management planning
(2)	AFTPAST	Pasture after nutrient management (current practices)
(3)	MANPAST	Pasture with manure only
(4)	COMMPAST	Pasture with only commercial fertilizer
(5)	IDLEPAST	Idle pasture

Table F.2 Crop Yields and Nutrient Losses for Fertilizer Management Alternatives: Corn, Barley, Soybean Rotation

Alternative/ Soil	Corn Yield (T/ac)	Barley Yield (T/ac)	Soybean/ Sudex Yield (T/ac)/(Bu/ac)	Eros-ion (T/ac)	Volatil-ization (lb./ac)	NO3 runoff (lb./ac)	Org. N w/sed. (lb./ac)	Min. N sub. flow (lb./ac)	Min. N Perc. (lb./ac)	Total N Loss[1] (lb./ac)	Sol. P runoff (lb./ac)	P Loss w/sed. (lb./ac)	Total P Loss (lb./ac)
BEFCBXFB	19.1	10.2	6.0	1.8	28.1	3.4	23.5	3.9	15.9	46.7	0.0	5.8	5.8
BEFCRCBFB	18.9	10.2	NA	2.2	13.0	3.7	13.6	3.5	3.4	24.1	0.0	4.4	4.4
AFTCBSFB	18.9	10.2	40.9	1.5	37.0	3.1	14.8	2.6	3.5	24.1	0.0	4.0	4.0
RYECBSFB	18.8	10.1	41.0	1.6	37.0	3.2	15.9	2.4	2.6	24.2	0.0	4.3	4.3
FALLCBSFB	18.9	10.1	40.9	1.5	36.8	3.4	15.6	3.0	4.1	26.1	0.0	4.3	4.3
CBS9FB	18.9	10.1	40.1	1.5	52.6	2.6	17.5	2.3	3.0	25.5	0.0	5.1	5.1
CBS12FB	19.0	10.2	42.2	1.5	69.1	2.9	19.7	2.7	3.9	29.2	0.0	5.8	5.8
CBS3FB	19.0	10.1	40.7	1.6	22.0	3.3	13.1	2.4	3.0	21.7	0.0	4.0	4.0
NOMANCBSFB	19.0	10.2	40.2	1.7	7.0	3.3	11.4	2.4	3.0	20.2	0.0	5.4	5.4
HIGHNCBSFB	19.1	10.2	40.8	1.7	7.9	3.5	11.5	2.7	4.0	21.6	0.0	5.4	5.4
SPLTNCBSFB	19.0	10.2	40.2	1.7	7.0	3.3	11.4	2.1	3.0	19.9	0.0	5.4	5.4
PLT30CBSFB	19.0	10.2	40.2	1.7	6.9	3.2	11.4	2.0	3.0	19.7	0.0	5.4	5.4
AUTOCBSFB	19.0	10.1	39.8	1.7	6.6	2.0	11.4	1.3	1.7	16.4	0.0	5.4	5.4
BEFCBXFC	18.9	10.2	5.9	11.1	28.1	5.0	82.9	7.8	7.8	103.5	0.0	22.3	22.3
BEFCRCBFC	18.8	10.1	NA	13.0	13.0	5.4	49.6	7.3	1.8	64.1	0.0	17.3	17.3
AFTCBSFC	18.8	10.1	39.8	9.3	37.1	4.4	55.6	5.4	1.9	67.3	0.0	15.8	15.8
RYECBSFC	18.6	10.1	39.9	9.9	37.1	4.5	58.0	4.9	1.4	68.8	0.0	16.6	16.6
FALLCBSFC	18.7	10.1	39.7	8.9	36.8	4.6	57.5	6.2	2.2	70.5	0.0	16.7	16.7
CBS9FC	18.7	10.1	39.1	8.9	52.6	3.5	65.0	4.6	1.6	74.8	0.0	19.9	19.9
CBS12FC	18.8	10.1	41.1	8.7	69.1	3.8	72.6	5.4	2.1	83.8	0.0	22.6	22.6
CBS3FC	18.8	10.1	39.6	9.6	22.0	4.6	49.5	4.9	1.7	60.7	0.0	15.9	15.9
NOMANCBSFC	18.8	10.1	39.2	10.0	7.0	4.8	43.2	5.0	1.6	54.6	0.0	21.1	21.1
HIGHNCBSFC	18.9	10.1	39.7	10.0	7.9	5.1	43.3	5.5	2.0	55.9	0.0	21.1	21.1
SPLTNCBSFC	18.8	10.1	39.2	10.0	6.9	4.6	43.2	4.4	1.7	53.8	0.0	21.1	21.1
PLT30CBSFC	18.9	10.1	39.3	10.0	6.9	4.4	43.2	4.2	1.7	53.5	0.0	21.1	21.1
AUTOCBSFC	18.8	10.1	38.2	10.0	6.2	2.5	43.1	2.5	0.9	49.0	0.0	20.8	20.8

[1] excluding volatilization

Table F.2 (continued)**: Crop Yields and Nutrient Losses for Fertilizer Management Alternatives: Corn, Barley, Soybean**

Alternative/ Soil	Corn Yield (T/ac)	Barley Yield (T/ac)	Soybean/ Sudex Yield (T/ac)/(Bu/ac)	Eros-ion (T/ac)	Volatil-ization (lb./ac)	NO3 runoff (lb./ac)	Org. N w/sed. (lb./ac)	Min. N sub. flow (lb./ac)	Min. N Perc. (lb./ac)	Total N Loss[1] (lb./ac)	Sol. P runoff (lb./ac)	P Loss w/sed. (lb./ac)	Total P Loss (lb./ac)
BEFCBXN	12.3	8.2	3.8	0.2	26.5	5.2	7.9	7.6	90.5	111.2	0.3	1.9	2.2
BEFCRCBN	12.1	8.1	NA	0.2	12.3	5.1	5.2	7.8	74.5	92.6	0.2	1.5	1.8
AFTCBSN	12.3	7.8	27.1	0.1	34.7	4.5	5.4	5.3	63.2	78.4	0.2	1.4	1.6
RYECBSN	12.3	7.8	27.1	0.1	34.7	4.4	5.6	5.0	56.3	71.3	0.2	1.5	1.7
FALLCBSN	11.9	7.8	27.1	0.1	34.8	4.4	5.7	5.6	70.5	86.2	0.2	1.5	1.8
CBS9N	12.2	7.3	27.1	0.1	49.6	3.8	6.2	4.5	56.6	71.1	0.3	1.7	2.0
CBS12N	12.3	7.8	27.2	0.1	65.2	4.1	6.7	5.0	65.0	80.8	0.4	1.8	2.2
CBS3N	12.3	8.1	27.1	0.1	20.7	4.7	5.0	5.1	55.3	70.1	0.2	1.4	1.7
NOMANCBSN	12.2	8.1	27.0	0.1	6.7	4.7	4.6	5.2	56.0	70.5	0.5	1.6	2.1
HIGHNCBSN	12.3	8.1	27.0	0.1	7.5	4.9	4.6	5.8	64.0	79.3	0.5	1.6	2.1
SPLTNCBSN	12.4	8.1	27.0	0.1	6.6	4.5	4.6	4.5	54.1	67.6	0.5	1.6	2.1
PLT30CBSN	12.4	8.1	27.0	0.1	6.6	4.4	4.6	4.3	52.8	66.0	0.5	1.6	2.1
AUTOCBSN	12.4	8.2	27.1	0.1	5.4	2.7	4.6	2.6	33.7	43.5	0.4	1.6	2.1

[1] excludes volatilization

Table F.3: Crop Yields and Nutrient Losses for Fertilizer Management Alternatives: Corn, Wheat, Clover Rotation

Alternative/ Soil	Corn Yld (T/ac)	Wheat Yld (T/ac)	Erosion (T/ac)	Volatil- ization (lb./ac)	NO3 in runoff (lb./ac)	Organic N w/sediment (lb./ac)	Min. N sub. flow (lb./ac)	Min. N Percolate (lb./ac)	Total N Loss[1] (lb./ac)	Soluble P runoff (lb./ac)	P Loss w/sed. (lb./ac)	Total P Loss (lb./ac)
BEFCRFB	19.3	NA	1.9	11.0	3.3	13.9	3.7	3.7	24.6	0.0	7.3	7.4
AFTCWCFB	18.0	10.2	1.3	36.5	2.3	11.1	2.4	2.9	18.7	0.0	3.7	3.7
FALLCWCFB	17.9	10.2	1.2	36.2	2.4	10.9	2.4	2.8	18.6	0.0	3.7	3.7
CWC9FB	17.9	10.1	1.2	52.0	1.8	12.5	2.0	2.2	18.5	0.0	4.2	4.2
CWC12FB	18.1	10.2	1.2	69.1	2.1	14.0	2.7	4.2	23.0	0.0	4.6	4.6
CWC3FB	18.0	10.2	1.3	21.5	2.5	9.8	2.2	2.3	16.7	0.0	3.8	3.8
NOMANCWCFB	18.0	10.2	1.4	6.4	2.5	8.5	2.2	2.3	15.5	0.0	5.0	5.0
HIGHNCWCFB	18.1	10.2	1.4	7.3	2.6	8.6	2.6	3.1	16.9	0.0	5.0	5.0
SPLTNCWCFB	18.0	10.2	1.4	6.4	2.5	8.5	2.1	2.3	15.4	0.0	5.0	5.0
PLT30CWCFB	18.0	10.2	1.4	6.4	2.5	8.5	2.0	2.3	15.2	0.0	5.0	5.0
AUTOCWCFB	18.1	10.1	1.4	5.9	1.4	8.4	0.9	0.9	11.7	0.0	4.9	4.9
BEFCRFC	19.2	NA	12.3	11.0	6.0	45.0	7.7	2.0	60.7	0.1	28.8	28.8
AFTCWCFC	17.6	10.2	7.6	36.4	3.2	40.0	5.0	1.4	49.6	0.0	14.3	14.3
FALLCWCFC	17.5	10.2	7.3	36.2	3.3	39.4	5.0	1.4	49.1	0.0	13.9	13.9
CWC9FC	17.5	10.1	7.2	51.9	2.3	45.4	4.1	1.1	52.9	0.0	16.1	16.1
CWC12FC	17.7	10.2	7.1	69.0	2.8	50.8	5.5	2.0	61.0	0.0	17.7	17.7
CWC3FC	17.6	10.2	7.8	21.4	3.4	35.4	4.5	1.3	44.5	0.0	14.7	14.7
NOMANCWCFC	17.6	10.2	8.2	6.4	3.5	30.5	4.6	1.2	39.9	0.0	18.8	18.8
HIGHNCWCFC	17.7	10.2	8.2	7.3	3.7	30.7	5.4	1.6	41.5	0.0	18.9	18.9
SPLTNCWCFC	17.6	10.2	8.2	6.4	3.5	30.5	4.4	1.2	39.6	0.0	18.8	18.8
PLT30CWCFC	17.6	10.2	8.2	6.4	3.5	30.5	4.2	1.2	39.4	0.0	18.9	18.9
AUTOCWCFC	17.7	10.1	8.1	5.9	1.9	30.3	1.9	0.5	34.6	0.0	18.7	18.8
BEFCR	11.4	NA	0.2	10.5	5.0	5.5	8.0	84.4	102.9	0.6	2.3	2.9
AFTCWCN	12.3	7.2	0.1	34.2	4.0	4.0	4.5	48.4	60.9	0.2	1.2	1.4
FALLCWCN	12.0	7.2	0.1	34.3	3.7	4.0	4.6	52.7	65.1	0.2	1.2	1.4
CWC9N	12.3	6.7	0.1	49.0	3.2	4.5	3.7	41.4	52.8	0.3	1.3	1.6
CWC12N	12.4	7.3	0.1	65.2	3.7	4.9	4.6	55.5	68.6	0.4	1.4	1.8
CWC3N	12.3	7.7	0.1	20.2	4.2	3.7	4.4	41.7	54.0	0.2	1.2	1.4
NOMANCWCN	12.3	7.7	0.1	6.1	4.2	3.3	4.5	42.8	54.9	0.4	1.3	1.8
HIGHNCWCN	12.4	7.7	0.1	6.9	4.4	3.3	5.1	51.2	64.0	0.4	1.3	1.8
SPLTNCWCN	12.4	7.7	0.1	6.1	4.1	3.3	4.1	41.8	53.2	0.4	1.3	1.8
PLT30CWCN	12.4	7.7	0.1	6.1	4.0	3.3	3.9	40.7	52.0	0.4	1.3	1.8
AUTOCWCN	12.4	7.9	0.1	4.7	2.2	3.3	1.7	18.4	25.7	0.4	1.3	1.8

[1] excluding volatilization.

Table F.4: Crop Yields and Nutrient Losses for Fertilizer Management Alternatives: Corn, Barley, Alfalfa Rotation

Alternative/ Soil	Alfalfa Yield (T/ac)	Corn Yield (T/ac)	Barley Yield (T/ac)	Soybean/ Sudex Yld (T/ac)/(Bu/ac)	Eros -ion (T/ac)	Volatil- ization (lb./ac)	NO3 runoff (lb./ac)	Org. N w/sed. (lb./ac)	Min. N sub. flow (lb./ac)	Min. N Perc. (lb./ac)	Total N Loss[1] (lb./ac)	Sol. P runoff (lb./ac)	P Loss w/sed. (lb./ac)	Total P Loss (lb./ac)
BEFCBAFB	4.5	19.6	10.2	5.2	0.9	5.2	3.2	6.1	2.2	4.1	15.5	0.0	3.2	3.2
AFTCBAFB	4.6	19.0	10.1	41.4	0.9	18.6	3.5	8.3	2.2	2.9	16.8	0.0	2.5	2.6
RYECBAFB	4.6	18.9	10.1	41.4	0.9	18.6	3.6	8.6	2.1	2.4	16.8	0.0	2.6	2.7
FALLCBAFB	4.6	19.0	10.1	41.4	0.8	18.5	3.6	8.6	2.3	3.1	17.7	0.0	2.7	2.7
CBA9FB	4.4	19.0	10.1	41.1	0.8	26.4	3.1	9.6	1.9	2.4	17.1	0.0	3.0	3.0
CBA12FB	4.4	19.0	10.1	41.5	0.8	34.6	3.3	10.5	2.2	3.1	19.0	0.0	3.3	3.3
CBA3FB	4.5	18.9	10.1	41.5	0.9	11.2	3.6	7.6	2.0	2.8	15.9	0.0	2.5	2.5
NOMANCBAFB	4.4	18.9	10.1	41.5	0.9	3.7	3.6	6.9	2.0	3.0	15.6	0.0	3.3	3.3
HIGHNCBAFB	4.4	18.9	10.1	41.7	0.9	4.1	3.7	6.9	2.1	4.5	17.3	0.0	3.3	3.3
SPLTNCBAFB	4.4	18.9	10.1	41.5	0.9	3.7	3.6	6.9	1.9	3.1	15.5	0.0	3.3	3.3
PLT30CBAFB	4.4	18.9	10.1	41.5	0.9	3.7	3.6	6.9	1.9	3.2	15.5	0.0	3.3	3.3
AUTOCBAFB	4.4	19.1	10.1	41.4	0.9	3.4	2.8	6.9	1.4	1.6	12.8	0.0	3.3	3.3
BEFCBAFC	4.4	19.4	10.2	4.9	5.5	5.2	4.1	22.0	4.6	2.0	32.7	0.1	12.4	12.5
AFTCBAFC	4.5	18.8	10.1	40.9	5.3	18.6	4.5	30.0	4.4	1.5	40.4	0.1	10.0	10.0
RYECBAFC	4.5	18.8	10.1	40.9	5.4	18.6	4.6	31.2	4.2	1.2	41.3	0.1	10.3	10.4
FALLCBAFC	4.5	18.8	10.1	40.9	5.1	18.5	4.6	30.8	4.8	1.6	41.8	0.1	10.4	10.4
CBA9FC	4.3	18.8	10.0	40.6	5.1	26.3	4.0	34.5	3.9	1.3	43.7	0.1	11.7	11.8
CBA12FC	4.3	18.8	10.1	41.1	5.0	34.6	4.1	37.7	4.3	1.6	47.8	0.1	12.8	12.9
CBA3FC	4.4	18.8	10.1	41.0	5.4	11.2	4.7	27.5	4.1	1.4	37.7	0.1	10.0	10.0
NOMANCBAFC	4.3	18.7	10.1	41.0	5.6	3.7	4.7	25.0	4.1	1.5	35.3	0.1	12.8	12.9
HIGHNCBAFC	4.3	18.7	10.1	41.2	5.6	4.1	4.8	25.0	4.4	2.3	36.5	0.1	12.8	12.9
SPLTNCBAFC	4.3	18.7	10.1	41.1	5.6	3.7	4.6	25.0	3.9	1.6	35.0	0.1	12.8	12.9
PLT30CBAFC	4.3	18.7	10.1	41.1	5.6	3.7	4.5	25.0	3.8	1.6	34.9	0.1	12.8	12.9
AUTOCBAFC	4.3	19.0	10.1	41.1	5.5	3.4	3.5	24.9	2.9	0.9	32.2	0.1	12.8	12.8
BEFCBAN	3.3	12.2	7.9	3.6	0.1	5.0	3.4	2.5	4.2	49.8	59.9	0.5	0.9	1.5
AFTCBAN	3.3	12.1	7.7	26.0	0.1	17.5	3.5	3.1	3.7	48.1	58.4	0.4	0.9	1.2
RYECBAN	3.3	12.2	7.7	26.0	0.1	17.5	3.5	3.1	3.6	44.9	55.1	0.4	0.9	1.3
FALLCBAN	3.3	11.8	7.7	26.0	0.1	17.5	3.5	3.2	3.9	51.3	61.8	0.4	0.9	1.3
CBA9N	3.2	12.1	7.1	26.0	0.1	24.9	3.1	3.4	3.2	43.8	53.6	0.4	1.0	1.4
CBA12N	3.2	12.1	7.7	26.0	0.1	32.8	3.2	3.7	3.5	48.4	58.8	0.5	1.1	1.5
CBA3N	3.3	12.1	8.1	26.0	0.1	10.5	3.6	2.9	3.6	43.6	53.8	0.4	0.9	1.2
NOMANCBAN	3.3	12.1	8.1	26.0	0.1	3.5	3.6	2.7	3.7	44.1	54.1	0.5	1.0	1.5
HIGHNCBAN	3.3	12.1	8.1	26.0	0.1	3.9	3.7	2.7	3.9	47.7	58.0	0.5	1.0	1.5
SPLTNCBAN	3.3	12.2	8.1	26.0	0.1	3.5	3.5	2.7	3.3	43.3	52.8	0.5	1.0	1.5
PLT30CBAN	3.3	12.2	8.1	26.0	0.1	3.5	3.4	2.7	3.2	42.6	51.9	0.5	1.0	1.5
AUTOCBAN	3.3	12.5	8.1	26.0	0.1	3.0	2.6	2.7	2.3	32.6	40.2	0.5	1.0	1.5

[1] excluding volatilization

Table F.5: Yield and Nutrient Losses for Fertilizer Management Alternatives: Continuously Grazed Pasture

Alternative/ Soil	Pasture Yield (T/ac)	Erosion (T/ac)	Volatilization (lb./ac)	NO3 in runoff (lb./ac)	Organic N w/sediment (lb./ac)	Min. N sub. flow (lb./ac)	Min. N Percolate (lb./ac)	Total N Loss[1] (lb./ac)	Soluble P runoff (lb./ac)	P Loss w/sed. (lb./ac)	Total P Loss (lb./ac)
BEFPASTFB	0.5	.7	38.5	1.5	39.7	2.0	25.2	68.3	1.3	8.5	9.8
AFTPASTFB	0.5	0.7	9.6	1.1	11.3	1.5	9.8	23.7	0.0	3.4	3.4
MANPASTFB	0.5	0.8	17.7	0.9	22.3	0.5	3.2	26.9	0.1	5.5	5.6
COMPASTFB	0.5	0.9	4.5	1.2	6.1	1.9	12.8	22.0	0.0	3.7	3.7
BEFPASTFC	0.5	3.3	38.5	1.5	103.2	4.0	20.6	129.2	1.4	24.0	25.5
AFTPASTFC	0.5	3.3	9.6	1.2	30.2	3.2	7.6	42.2	0.0	9.9	9.9
MANPASTFC	0.5	3.7	17.7	0.8	57.8	1.2	2.1	61.9	0.1	15.9	16.0
COMPASTFC	0.5	4.3	4.5	1.2	17.1	3.9	10.5	32.8	0.0	11.5	11.5
BEFPASTFD	0.5	8.9	38.5	1.5	170.7	5.3	15.7	193.2	1.3	45.0	46.2
AFTPASTFD	0.5	9.5	9.6	1.3	54.2	4.3	5.5	65.4	0.0	19.7	19.7
MANPASTFD	0.5	10.4	17.7	0.8	98.3	1.5	1.4	102.0	0.1	31.3	31.4
COMPASTFD	0.5	12.1	4.5	1.4	33.5	5.2	8.6	48.8	0.0	24.2	24.2
BEFPASTFE	0.5	33.3	38.5	1.7	288.7	6.8	7.5	304.8	0.8	96.5	97.4
AFTPASTFE	0.5	38.2	9.6	1.4	116.7	5.5	3.1	126.6	0.0	51.6	51.6
MANPASTFE	0.5	48.7	17.8	0.9	197.4	1.7	1.0	201.0	0.0	81.3	81.3
COMPASTFE	0.5	44.9	4.5	1.6	87.6	7.9	5.8	102.9	0.0	61.5	61.5

[1] excluding volatilization

Table F.6: Nutrient Losses for Idle Cropland and Pasture

Alternative/ Soil	Erosion (T/ac)	Volatilization (lb/ac)	NO3 in runoff (lb/ac)	Organic N w/sediment (lb/ac)	Min. N subsuface flow (lb/ac)	Min. N Percolate (lb/ac)	Total N Loss[1] (lb/ac)	Soluble P runoff (lb/ac)	P Loss w/sed. (lb/ac)	Total P Loss (lb/ac)
IDLCRPB	0.1	0.0	0.9	2.5	2.3	6.0	11.8	0.0	0.7	0.7
IDLCRPC	0.6	0.0	1.2	9.8	4.9	3.9	19.8	0.0	2.9	2.9
IDLCRPN	0.0	0.0	1.5	2.3	2.9	41.4	48.1	0.0	0.5	0.5
IDLEPASTB	0.1	0.0	0.8	1.5	1.1	3.5	6.8	0.0	0.6	0.6
IDLEPASTC	0.6	0.0	1.0	5.7	2.3	2.4	11.5	0.0	2.6	2.6
IDLEPASTD	2.0	0.0	1.2	11.9	3.4	1.7	18.1	0.0	5.8	5.8
IDLEPASTE	7.8	0.0	1.4	25.6	4.7	0.9	32.7	0.0	14.1	14.1

[1] excluding volatilization

Appendix G: Normality Tests of EPIC Generated Crop Yield and Nutrient Loss Distributions for Farm 2 LP Model

BEFCBXFB

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORN	19.075	.541	.0541	19.006	100
BARLEY	10.156	.610	.0610	10.120	100
SUDEX	5.970	.290	.0290	5.958	100
EROSION	1.828	.282	.0282	1.795	100
NLOSS	46.666	5.466	.5466	46.164	100
PLOSS	5.814	.794	.0794	5.767	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORN	1.0855	.58116	.0629	.82434

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
BARLEY	1.3752	.50277	.0586	.88203

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
SUDEX	.5553	.75755	.0608	.85402

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	1.7321	.42060	.0642	.80502

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	.1828	.91264	.0462	.98316

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	1.4408	.48655	.0611	.84965

BEFCBXFC

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORN	18.938	.555	.0555	18.870	100
BARLEY	10.152	.610	.0610	10.113	100
SUDEX	5.901	.296	.0296	5.875	100
EROSION	11.080	1.547	.1547	11.018	100
NLOSS	103.471	10.101	1.0101	102.304	100
PLOSS	22.334	2.583	.2583	22.242	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORN	1.0905	.57969	.0730	.66111

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
BARLEY	1.3861	.50004	.0587	.88060

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
SUDEX	.5214	.77050	.0547	.92622

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	.9629	.61788	.0722	.67467

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	.2408	.88656	.0628	.82547

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	.5922	.74372	.0701	.70942

BEFCBXN

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORN	12.343	.943	.0943	12.214	100
BARLEY	8.150	.542	.0542	8.168	100
SUDEX	3.847	.334	.0334	3.838	100
EROSION	.172	.023	.0023	.170	100
NLOSS	111.244	5.829	.5829	111.083	100
PLOSS	2.223	.317	.0317	2.214	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORN	2.7933	.24742	.0796	.55144

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
BARLEY	1.0731	.58475	.0382	.99861

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
SUDEX	.1929	.90804	.0426	.99350

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	1.6506	.43811	.0643	.80237

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	.3582	.83601	.0440	.99033

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	1.1325	.56765	.0392	.99789

BEFCRCBFB

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORN	18.926	.409	.0409	18.974	100
BARLEY	10.153	.606	.0606	10.120	100
EROSION	2.175	.322	.0322	2.173	100
NLOSS	24.133	2.926	.2926	23.983	100
PLOSS	4.395	.619	.0619	4.381	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORN	1.0150	.60199	.0766	.60050

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
BARLEY	1.3421	.51117	.0567	.90420

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	2.5428	.28044	.0544	.92900

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	3.1257	.20954	.0940	.34051

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	.0657	.96770	.0682	.74051

BEFCRCBFC

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORN	18.752	.422	.0422	18.796	100
BARLEY	10.142	.604	.0604	10.114	100
EROSION	12.954	1.777	.1777	12.916	100
NLOSS	64.061	6.349	.6349	64.206	100
PLOSS	17.346	2.235	.2235	17.282	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORN	1.3152	.51810	.0644	.80180

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
BARLEY	1.3741	.50305	.0570	.90179

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	1.8972	.38728	.0570	.90082

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	1.0053	.60491	.0532	.93961

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	.8061	.66827	.0454	.98607

BEFCRCBN

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORN	12.090	.631	.0631	12.082	100
BARLEY	8.096	.528	.0528	8.128	100
EROSION	.171	.022	.0022	.171	100
NLOSS	92.602	5.960	.5960	92.125	100
PLOSS	1.763	.266	.0266	1.782	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORN	.5188	.77152	.0465	.98189

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
BARLEY	.9234	.63020	.0521	.94891

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	1.1288	.56871	.0549	.92423

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	2.2039	.33222	.0827	.50073

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	.0378	.98128	.0675	.75210

BEFCBAFB

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORN	19.614	1.282	.1282	19.748	100
BARLEY	10.194	.700	.0700	10.193	100
SUDEX	5.187	.568	.0568	5.147	100
ALFALFA	4.472	.277	.0277	4.468	100
EROSION	.894	.190	.0190	.880	100
NLOSS	15.511	2.776	.2776	14.966	100
PLOSS	3.210	.558	.0558	3.128	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORN	1.2733	.52906	.0684	.73747

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
BARLEY	.3229	.85090	.0478	.97614

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
SUDEX	.4732	.78930	.0578	.89185

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
ALFALFA	1.0359	.59573	.0595	.87028

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	2.3545	.30812	.0679	.74587

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	20.2944	.00000	.1038	.23188

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	2.8928	.23542	.0833	.49080

BEFCBAFC

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORN	19.403	1.301	.1301	19.531	100
BARLEY	10.181	.696	.0696	10.162	100
SUDEX	4.884	.556	.0556	4.845	100
ALFALFA	4.408	.275	.0275	4.408	100
EROSION	5.478	1.072	.1072	5.325	100
NLOSS	32.744	4.352	.4352	31.966	100
PLOSS	12.522	1.887	.1887	12.424	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORN	1.2704	.52982	.0522	.94778

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
BARLEY	.3067	.85784	.0434	.99175

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
SUDEX	2.1471	.34180	.0538	.93392

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
ALFALFA	1.4049	.49537	.0441	.99011

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	2.2142	.33051	.0764	.60433

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	1.5833	.45310	.0849	.46733

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	2.4108	.29957	.0642	.80435

BEFCBAN

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORN	12.216	1.303	.1303	12.121	100
BARLEY	7.854	.632	.0632	7.940	100
SUDEX	3.576	.472	.0472	3.558	100
ALFALFA	3.346	.227	.0227	3.359	100
EROSION	.073	.013	.0013	.072	100
NLOSS	59.924	4.746	.4746	59.291	100
PLOSS	1.476	.232	.0232	1.459	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORN	2.5420	.28055	.0757	.61572

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
BARLEY	6.0645	.04821	.0859	.45108

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
SUDEX	1.4322	.48865	.0549	.92351

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
ALFALFA	1.6701	.43385	.0646	.79819

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	3.0740	.21502	.0716	.68366

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	1.2679	.53049	.0699	.71324

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	.8343	.65891	.0649	.79342

BEFCRFB

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORN	19.297	.385	.0385	19.279	100
EROSION	1.938	.290	.0290	1.919	100
NLOSS	24.637	2.661	.2661	24.656	100
PLOSS	7.373	1.116	.1116	7.384	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORN	.9933	.60856	.0524	.94645

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	2.0331	.36184	.0668	.76379

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	.6192	.73374	.0463	.98273

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	1.7879	.40904	.0474	.97816

BEFCRFC

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORN	19.152	.392	.0392	19.148	100
EROSION	12.275	1.681	.1681	12.210	100
NLOSS	60.718	5.385	.5385	60.932	100
PLOSS	28.849	3.833	.3833	28.658	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORN	.6531	.72140	.0424	.99389

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	1.4708	.47931	.0436	.99128

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	.7897	.67380	.0446	.98859

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	.6623	.71810	.0494	.96764

BEFCRN

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORN	11.351	.584	.0584	11.333	100
EROSION	.175	.022	.0022	.175	100
NLOSS	102.889	5.997	.5997	102.746	100
PLOSS	2.861	.388	.0388	2.860	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORN	1.2094	.54625	.0425	.99353

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	.4173	.81169	.0594	.87188

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	1.8091	.40472	.0647	.79628

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	.0943	.95395	.0603	.86010

AFTCBSFB

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORNYLD	18.948	.524	.0524	18.884	100
BARLYLD	10.150	.607	.0607	10.117	100
SOYYLD	40.936	2.888	.2888	40.738	100
EROSION	1.530	.245	.0245	1.532	100
NLOSS	24.095	2.950	.2950	23.886	100
PLOSS	4.007	.578	.0578	3.935	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORNYLD	1.2488	.53558	.0759	.61169

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
BARLYLD	1.4357	.48779	.0645	.79999

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
SOYYLD	.7319	.69353	.0539	.93309

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	2.3778	.30456	.0717	.68360

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	3.7580	.15274	.0654	.78644

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	1.9742	.37267	.0710	.69531

AFTCBSFC

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORN	18.769	.531	.0531	18.686	100
BARLEY	10.139	.605	.0605	10.110	100
SOYBEAN	39.848	2.959	.2959	39.680	100
EROSION	9.327	1.385	.1385	9.301	100
NLOSS	67.313	7.593	.7593	66.922	100
PLOSS	15.839	2.014	.2014	15.797	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORN	1.5616	.45805	.0814	.52132

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
BARLEY	1.4912	.47446	.0687	.73292

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
SOYBEAN	1.4729	.47881	.0440	.99028

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	1.8440	.39771	.0750	.62778

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	1.4172	.49232	.0630	.82220

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	1.4172	.49232	.0630	.82220

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	1.0837	.58168	.0598	.86734

AFTCBSN

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORNYLD	12.254	.902	.0902	12.137	100
BARLYLD	7.820	.483	.0483	7.818	100
SOYYLD	27.065	2.053	.2053	27.170	100
EROSION	.140	.019	.0019	.138	100
NLOSS	78.423	4.849	.4849	77.964	100
PLOSS	1.615	.253	.0253	1.606	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORNYLD	2.8487	.24067	.0731	.65867

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
BARLYLD	1.5726	.45553	.0539	.93373

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
SOYYLD	1.6221	.44439	.0458	.98478

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	1.9462	.37790	.0555	.91816

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	2.0983	.35023	.0656	.78321

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	2.7578	.25186	.0658	.77999

AFTCBAFB

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORNYLD	18.958	.677	.0677	18.957	100
BARLYLD	10.096	.741	.0741	10.066	100
SOYYLD	41.418	3.644	.3644	41.626	100
ALFYLD	4.571	.283	.0283	4.580	100
EROSION	18.638	.194	.0194	18.647	100
NLOSS	16.819	2.343	.2343	16.635	100
PLOSS	2.551	.431	.0431	2.502	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORNYLD	1.2288	.54096	.0561	.91148

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
BARLYLD	.5659	.75357	.0653	.78739

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
SOYYLD	1.8654	.39349	.0755	.61830

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
ALFYLD	1.5303	.46527	.0580	.88947

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	.5927	.74351	.0399	.99732

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	2.6481	.26605	.0599	.86625

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	2.1804	.33615	.0932	.35073

AFTCBAFC

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORNYLD	18.802	.691	.0691	18.812	100
BARLYLD	10.088	.737	.0737	10.061	100
SOYYLD	40.941	3.619	.3619	41.160	100
ALFYLD	4.488	.281	.0281	4.498	100
EROSION	5.291	.959	.0959	5.115	100
NLOSS	40.384	5.181	.5181	39.913	100
PLOSS	10.040	1.507	.1507	9.795	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORNYLD	1.0596	.58872	.0556	.91627

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
BARLYLD	.5435	.76205	.0611	.84876

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
SOYYLD	1.5837	.45301	.0809	.53016

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
ALFYLD	1.4109	.49389	.0473	.97861

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	2.6649	.26383	.0983	.28895

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	1.1438	.56446	.0595	.87047

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	1.3240	.51582	.0726	.66745

AFTCBAN

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORNYLD	12.093	1.067	.1067	11.974	100
BARLYLD	7.701	.579	.0579	7.769	100
SOYYLD	25.998	3.409	.3409	26.253	100
ALFYLD	3.341	.235	.0235	3.366	100
EROSION	.079	.013	.0013	.078	100
NLOSS	58.388	4.070	.4070	58.399	100
PLOSS	1.245	.213	.0213	1.224	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORNYLD	1.8149	.40355	.1004	.26608

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
BARLYLD	4.4542	.10784	.0952	.32484

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
SOYYLD	2.4370	.29567	.0813	.52236

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
ALFYLD	1.2694	.53008	.0814	.52113

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	3.5322	.17100	.0685	.73605

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	2.3544	.30814	.0830	.49635

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	2.7848	.24848	.0698	.71463

AFTCWCFB

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORN	17.962	.850	.0850	18.050	100
WHEAT	10.180	.619	.0619	10.183	100
EROSION	1.277	.256	.0256	1.255	100
NLOSS	18.659	2.700	.2700	18.340	100
PLOSS	3.728	.679	.0679	3.659	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORN	4.5617	.10220	.0510	.95688

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
WHEAT	1.3345	.51313	.0474	.97826

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	1.9704	.37336	.0695	.71902

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	1.9201	.38288	.0762	.60690

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	2.0436	.35996	.0559	.91353

AFTCWCFC

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORN	17.577	1.025	.1025	17.645	100
WHEAT	10.177	.616	.0616	10.182	100
EROSION	7.577	1.413	.1413	7.360	100
NLOSS	49.619	6.932	.6932	49.361	100
PLOSS	14.316	2.330	.2330	14.015	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORN	1.6944	.42862	.0510	.95751

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
WHEAT	1.3211	.51657	.0475	.97754

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	1.5865	.45236	.0854	.45965

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	.8503	.65369	.0398	.99742

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	1.4482	.48476	.0614	.84556

AFTCWCN

Descriptive Statistics

Variable	Mean	Std. Dev.	S.E.of Mean	Median	Cases
CORN	12.292	.904	.0904	12.186	100
WHEAT	7.175	.506	.0506	7.214	100
EROSION	.111	.018	.0018	.109	100
NLOSS	60.938	3.623	.3623	60.477	100
PLOSS	1.351	.239	.0239	1.346	100

Normality Tests

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
CORN	2.5811	.27512	.0659	.77754

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
WHEAT	1.2491	.53550	.0636	.81401

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
EROSION	1.2930	.52388	.0666	.76632

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
NLOSS	.2763	.87099	.0697	.71568

Variable	Chi-squared	P-Value	Kolmogorov-Smirnov	P-Value
PLOSS	1.4084	.49449	.0836	.48647

Appendix H: Crop Rotations, Crop Production, and Crop Sales Before and After Nutrient Management Planning for Farm 2

In constraining the model to the rotations used before and after the adoption of the nutrient management plan, it is assumed that the amount of each soil in each rotation is directly proportional to the amount of each soil found on the farm as a whole (see Table H.1).

One change in farm income is not reflected in the model. Prior to the adoption of the nutrient management plan, only 85 dairy cows were present on the farm. However, 160 dairy cows are currently milked. While this change results in a higher milk production, higher feed ration requirements, and more manure production, it is not a change resulting from the implementation of the plan. Therefore, it is assumed in modeling the two scenarios that livestock numbers have been constant as far as feed requirements, manure production, and milk production are concerned.

Before the implementation of the plan, semi-solid manure was spread on the home pasture and 38 acres of cropland. Home pasture received approximately 15 T/ac annually while fields H13 and H14 received approximately 8.4 T/ac annually.[40] The rest of the fields received only commercial fertilizer application. Prior to the adoption of nutrient management planning, the farm only had 85 dairy cows. However, dairy cow numbers have now increased to 160 (a factor of 1.88). However, this increase in livestock numbers is not a result of the nutrient management plan. Therefore, in an attempt to isolate the impacts of the plan, it will be assumed that manure production before the plan was also 1.88 times greater. For the EPIC simulations, it is assumed that all manure would have been applied to the same fields but at higher application rates.

Table H.1: Crop Rotations and Fertilizer Management Practices Before Plan[1]

Alternative	Acres	Alternative	Acres
BEFCRFB	18.2	BEFPASTB	5
BEFCRFC	28.6	BEFPASTC	20
BEFCRN	5.2	BEFPASTD	5
BEFCBXFB	13.3	BEFPASTE	20
BEFCBXFC	20.9		
BEFCBXN	3.8		
BEFCRCBFB	11.55		
BEFCRCBFC	18.15		
BEFCRCBN	3.3		
BEFCBAFB	49.35		
BEFCBAFC	77.55		
BEFCBAN	14.1		
Total Cropland	**264**	**Total Pasture**	**50**

[1] see Tables 4.3, 4.4, 4.5, and 4.7 for description of alternatives.

[40] Unless otherwise indicated, manure application rates are expressed on wet basis as spread.

Table H.2: Crop Rotations and Fertilizer Management Practces After Plan[1]

Alternative	Acres	Alternative	Acres
AFTCWCFB	18.2	AFTPASTB	5
AFTCWCFC	28.6	AFTPASTC	20
AFTCWCN	5.2	AFTPASTD	5
AFTCBSFB	24.9	AFTPASTE	20
AFTCBSFC	38.1		
AFTCBSN	7.1		
AFTCBAFB	49.4		
AFTCBAFC	77.6		
AFTCBAN	14.1		
Total Cropland	**264**	**Total Pasture**	**50**

[1] see Tables 4.3, 4.4, 4.5, and 4.7 for description of alternatives.

Table H.3: Total Crop Production Before and After Plan

Crop	Before Plan	After Plan
Corn Silage (Tons)	2662.367	1826.213
Barley Silage (Tons)	755.538	748.881
Wheat Silage (Tons)		257.400
Soybeans (Bushels)		2577.466
Alfalfa Hay (Tons)	261.442	266.751
Sudex Hay (Tons)	256.049	0

Table H.4: Buying and Selling Activities Before Plan

Product	Amount Purchased (Tons)[2]	Amount Sold (Tons)
Corn Silage		1442.367
Barley /Wheat Silage		362.906
Sudex Hay		256.049
Alfalfa Hay	55.758	
Soybeans[3]	97.600	
Corn Grain	258.455	
Barley Grain	100.361	
Distillers Grain	109.808	
Broiler Litter	29.748	
Milk		30880

[2] amount of milk sold is by hundred weight rather than tons.

[3] Although soybean production is reported in bushels, all production is converted to tons for use in feed ration constraints.

Table H.5: Buying and Selling Activities After Plan

Product	Amount Purchased (Tons)[2]	Amount Sold (Tons)
Corn Silage		616.213
Barley /Wheat Silage		613.649
Sudex Hay		
Alfalfa Hay	50.449	
Soybeans[3]	20.276	
Corn Grain	258.455	
Barley Grain	100.361	
Distillers Grain	109.808	
Broiler Litter	29.748	
Milk		30880

[2] amount of milk sold is by hundred weight rather than tons.
[3] Although soybean production is reported in bushels, all production is converted to tons for use in feed ration constraints.

Appendix I: Crop Rotations, Crop Production, and Crop Sales with Flexible Rotations and Fertilizer Management for Farm 2

Table I.1 : Crop Rotations and Fertilizer Management Practices (Acres), Flexible Rotations

Alternative	Unrestricted N Loss	10 % reduction	20 % reduction	30 % reduction	40 % reduction	50% reduction	60 % reduction
AFTCBSFB		63.9	63.9				
AFTCBSFC	123.0						
AFTCBAFC		12.8	98.0	29.3			
CBS9FB				11.9	66.7	71.8	23.0
CBA9FB							57
CBS12FB		28.5	28.5	80.5	25.7		
CBS3FB	92.4						
CBS3FC	22.2	132.4	47.2				
CBS3N	26.4						
AUTOCWCN					26.4	26.4	26.4
AUTOCBSFB						20.6	12.3
AUTOCBSN		26.4	26.4				
AUTOCBAFC				115.9	145.2	95.7	10.3
AUTOCBAN				26.4			
IDLECROPFC						49.5	134.9
BEFPASTB							
AFTPASTB	5.0						
AFTPASTC	20.0	12.5	12.5	9.4	16.2	14.8	7.0
AFTPASTD	5.0	5	5				
AFTPASTE	20.0						
COMMPASTB							
COMMPASTC						5.2	8.0
COMMPASTD				5.0	5.0	2.8	
COMMPASTE		20.0	20.0	20.0	9.1		
MANPASTB		5.0	5.0	5.0	5.0	5.0	5.0
MANPASTC		7.5	7.5	10.6	3.8		
IDLEPASTC							5.0
IDLEPASTD						2.2	5.0
IDLEPASTE					10.8	20.0	20.0

[1] see Tables 4.3, 4.4, and 4.6 for description of alternatives.

Table I.2 : Total Crop Production, Unrestricted Rotations

Crop	Unrestricted N Loss	10 % reduction	20 % reduction	30 % reduction	40 % reduction	50% reduction	60 % reduction
Corn Silage (Tons)	2405.04	2351.72	2008.16	1758.08	1826.44	1557.63	863.63
Barley Silage (Tons)	1306.80	1285.11	1100.58	950.78	886.96	742.91	372.69
Wheat Silage (Tons)					104.28	104.28	104.28
Soybeans (Bushels)	5125.32	4999.86	4059.81	3361.77	3158.41	2692.65	1299.17
Alfalfa Hay (Tons)		24.63	189.12	307.45	267.60	176.437	126.67
Sudex Hay (Tons)							

Table I.3: Buying and Selling Activities Unrestricted N Loss

Product	Amount Purchased (Tons)[2]	Amount Sold (Tons)
Corn Silage		1185.040
Barley /Wheat Silage		914.168
Sudex Hay		
Alfalfa Hay	317.200	
Soybeans[3]		56.160
Corn Grain	258.455	
Barley Grain	100.361	
Distillers Grain	109.808	
Broiler Litter	29.748	
Milk		30880

[2] Amount of milk sold is by hundred weight rather than tons.
[3] Although soybean production is reported in bushels, all production is converted to tons for use in feed ration constraints.

Table I.4: Buying and Selling with 10 % N Loss Reduction

Product	Amount Purchased (Tons)[2]	Amount Sold (Tons)
Corn Silage		1131.715
Barley /Wheat Silage		892.474
Sudex Hay		
Alfalfa Hay	292.567	
Soybeans[3]		52.396
Corn Grain	258.455	
Barley Grain	100.361	
Distillers Grain	109.808	
Broiler Litter	29.748	
Milk		30880

[2] Amount of milk sold is by hundred weight rather than tons.
[3] Although soybean production is reported in bushels, all production is converted to tons for use in feed ration constraints.

Table I.5: Buying and Selling with 20 % N Loss Reduction

Product	Amount Purchased (Tons)[2]	Amount Sold (Tons)
Corn Silage		788.158
Barley /Wheat Silage		707.164
Sudex Hay		
Alfalfa Hay	128.079	
Soybeans[3]		24.164
Corn Grain	258.455	
Barley Grain	100.361	
Distillers Grain	109.808	
Broiler Litter	29.748	
Milk		30880

[2] Amount of milk sold is by hundred weight rather than tons.
[3] Although soybean production is reported in bushels, all production is converted to tons for use in feed ration constraints.

Table I.6: Buying and Selling with 30 % N Loss Reduction

Product	Amount Purchased (Tons)[2]	Amount Sold (Tons)
Corn Silage		528.075
Barley /Wheat Silage		558.152
Sudex Hay		
Alfalfa Hay	9.750	
Soybeans[3]		3.253
Corn Grain	258.455	
Barley Grain	100.361	
Distillers Grain	109.808	
Broiler Litter	29.748	
Milk		30880

[2] Amount of milk sold is by hundred weight rather than tons.
[3] Although soybean production is reported in bushels, all production is converted to tons for use in feed ration constraints.

Table I.7: Buying and Selling with 40 % N Loss Reduction

Product	Amount Purchased (Tons)[2]	Amount Sold (Tons)
Corn Silage		871.466
Barley /Wheat Silage		683.896
Sudex Hay		
Alfalfa Hay		19.311
Soybeans[3]		18.355
Corn Grain	202.309	
Barley Grain	78.559	
Distillers Grain	85.954	
Broiler Litter	23.286	
Milk		24171.726

[2] Amount of milk sold is by hundred weight rather than tons.
[3] Although soybean production is reported in bushels, all production is converted to tons for use in feed ration constraints.

Table I.8: Buying and Selling with 50 % N Loss Reduction

Product	Amount Purchased (Tons)[2]	Amount Sold (Tons)
Corn Silage		879.027
Barley /Wheat Silage		628.793
Sudex Hay		
Alfalfa Hay		
Soybeans[3]		26.491
Corn Grain	143.761	
Barley Grain	55.824	
Distillers Grain	61.079	
Broiler Litter	16.547	
Milk		17176.418

[2] Amount of milk sold is by hundred weight rather than tons.
[3] Although soybean production is reported in bushels, all production is converted to tons for use in feed ration constraints.

Table I.9: Buying and Selling with 60 % N Loss Reduction

Product	Amount Purchased (Tons)[2]	Amount Sold (Tons)
Corn Silage		376.444
Barley /Wheat Silage		320.183
Sudex Hay		
Alfalfa Hay		
Soybeans[3]		
Corn Grain	103.21	
Barley Grain	40.078	
Distillers Grain	43.850	
Broiler Litter	11.879	
Milk		12331.441

[2] Amount of milk sold is by hundred weight rather than tons.

[3] Although soybean production is reported in bushels, all production is converted to tons for use in feed ration constraints.

Appendix J: Crop Rotations, Crop Production, and Crop Sales with Restricted Crop Rotations for Farm 2

Table J.1 : Fertilizer Management Practices with Current Crop Rotation Restriction

Alternative	Unrestricted N Loss	20 % reduction [a]	26 % reduction [a]
AFTCWCFB	18.2		
AFTCWCFC	28.6	28.6	
AFTCBSFB	15.2	3.1	
AFTCBSFC	39.1	1.8	
AFTCBAFB	49.4	49.4	
AFTCBAFC	77.6	77.6	41.8
CWC9FB		18.2	11.5
CWC9FC			28.6
CWC12FB			6.7
CBS12FB	9.7	21.8	24.9
CBA12FB			49.4
CWC3N	5.2		
CBS3FC		37.2	
CBS3N	7.1	7.1	
CBA3N	14.1	14.1	
AUTOCWCN		5.2	5.2
AUTOCBSFC			39.1
AUTOCBSN			7.1
AUTOCBAFC			35.8
AUTOCBAN			14.1
BEFPASTB			
AFTPASTB	5.0		
AFTPASTC	20.0	20.0	9.4
AFTPASTD	5.0	5.0	
AFTPASTE	20.0	12.0	
COMMPASTD			5.0
COMMPASTE		8.0	20.0
MANPASTB		5.0	5.0
MANPASTC			10.6

[a] Reduction in comparison to unrestricted crop rotation selection.

Table J.2: Total Crop Production with Current Crop Rotation Restriction

Crop	Unrestricted N Loss	20 % reduction [a]	26 % reduction [a]
Corn Silage (Tons)	1826.7	1826.7	1830.1
Barley Silage (Tons)	751.6	751.6	751.9
Wheat Silage (Tons)	258.7	258.3	257.2
Soybeans (Bushels)	2583.8	2587.9	2565.0
Alfalfa Hay (Tons)	266.8	266.8	259.5
Sudex Hay (Tons)	0	0	0

[a] Reduction in comparison to unrestricted crop rotation selection.

Table J.3: Buying and Selling Activities with Unrestricted N Loss, Current Crop Rotation Restriction

Product	Amount Purchased (Tons)[2]	Amount Sold (Tons)
Corn Silage		606.7
Barley /Wheat Silage		617.6
Sudex Hay		
Alfalfa Hay	50.5	
Soybeans[3]	20.1	
Corn Grain	258.5	
Barley Grain	100.4	
Distillers Grain	109.8	
Broiler Litter	29.7	
Milk		30880.0

[2] amount of milk sold is by hundred weight rather than tons.
[3] Although soybean production is reported in bushels, all production is converted to tons for use in feed ration constraints.

Table J.4: Buying and Selling Activities with 20 % Reduction in N Loss, Current Crop Rotation Restriction

Product	Amount Purchased (Tons)[2]	Amount Sold (Tons)
Corn Silage		606.7
Barley /Wheat Silage		617.2
Sudex Hay		
Alfalfa Hay	50.4	
Soybeans[3]	20.0	
Corn Grain	258.5	
Barley Grain	100.4	
Distillers Grain	109.8	
Broiler Litter	29.7	
Milk		30880.0

[2] amount of milk sold is by hundred weight rather than tons.
[3] Although soybean production is reported in bushels, all production is converted to tons for use in feed ration constraints.

Table J.5: Buying and Selling Activities with 26 % Reduction in N Loss, Current Crop Rotation Restriction

Product	Amount Purchased (Tons)[2]	Amount Sold (Tons)
Corn Silage		610.1
Barley /Wheat Silage		616.5
Sudex Hay		
Alfalfa Hay	57.7	
Soybeans[3]	20.7	
Corn Grain	258.5	
Barley Grain	100.4	
Distillers Grain	109.8	
Broiler Litter	29.7	
Milk		30880.0

[2] amount of milk sold is by hundred weight rather than tons.
[3] Although soybean production is reported in bushels, all production is converted to tons for use in feed ration constraints.

Appendix K: Crop Rotations for Sensitivity Analysis

Table K.1 : Crop Rotations / Fertilizer Management Practices (Acres), Sensitivity Analysis

Alternative	10 % increase in livestock	20 % increase in livestock
AFTCBSFB		
AFTCBSFC		
AFTCBAFC		94.8
CWC9FC	18.7	
CWC12FB	66.4	
CBS12FB	26.0	92.4
CBS3FB		
CBS3FC		
CBS3N		
AUTOCWCN	26.4	26.4
AUTOCBSN		
AUTOCBAFC	30.7	24.6
IDLECROPFC	95.8	25.8
AFTPASTB		
AFTPASTC	6.3	3.1
AFTPASTD		
AFTPASTE		
COMMPASTD	5.0	5.0
COMMPASTE	20.0	20.0
MANPASTB	5.0	5.0
MANPASTC	13.8	16.9

Vita

Laura Snively VanDyke was born on July 13, 1970 in Fort Lauderdale, Florida. After graduating from high school in Broadway, Virginia, she attended Virginia Tech, receiving a Bachelor of Arts degree in Liberal Arts and Sciences in 1992. After graduation, she worked in fundraising and as a photographer. She returned to Virginia Tech in 1994 to pursue a master's degree in Agriculture and Applied Economics.

Laura married Joseph VanDyke in 1995, they live in Blacksburg with their son James. Laura is currently working as a Research Associate for the Department of Agriculture and Applied Economics at Virginia Tech.