8-1992

An economic and environmental analysis of potential water quality regulations on dairy farms in the Big Limestone Watershed

Gary Bullen

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Date July 30 1992

AN ECONOMIC AND ENVIRONMENTAL ANALYSIS OF POTENTIAL WATER QUALITY REGULATIONS ON DAIRY FARMS IN THE BIG LIMESTONE WATERSHED

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

STEPHEN GARY BULLEN

August, 1992

DEDICATION

This thesis is dedicated to my wife and children

Carolyn Janelle Bullen

Nathan Wade Bullen and Elisa Beth Bullen

whose understanding and support made this possible.

ACKNOWLEDGEMENT

Many people contributed to the development and completion of this thesis. The author wishes to express his sincere gratitude to Dr. Burton English, major professor, for his encouragement, patience, and guidance, which made this thesis possible. Appreciation is also extended to Dr. William Park, and Dr. Greg Pompelli for serving on the authors graduate committee and for their assistance.

Further appreciation goes to Dr. Timothy Burcham, Water Quality Specialist, for his assistance in the waste management system budgets and labor requirements. Acknowledgment is also due to Dr. Paul Denton, Soil Scientist, for his assistance in developing soil data and reviewing EPIC results. The author also wishes to express his appreciation to Jose Valelasque for his assistance in GAMS modelling, and to Mahadev Bhat for his assistance with EPIC and for answering the authors many questions.

ABSTRACT

Recently, greater environmental awareness has resulted in placing greater value on the proper management of animal waste. Dairy farmers have become concerned about the possibilities of future regulations that may affect their farm income. Nitrates associated with agricultural practices is a major water quality concern. Dairy farms in particular have been cited as contributors to the water quality degradation because of animal waste and high use of nitrogen fertilizer. Best Management Practices (BMP) have been developed to address the unique issues associated with nonpoint source pollution. BMP's to control animal waste are usually associated with some type of waste storage. It is generally accepted the storage structures will allow better timing of manure disposal, thus reducing nitrogen loss.

This study examined the effects farm income effects on including a waste storage system. Most dairy farms in East Tennessee do not have a waste storage system. A recent survey found less than 70 percent of dairies used a daily haul system. The specific objectives of the study were to develop a linear programming model to evaluate the farm level effects of adding a waste storage system. The third objective was to evaluate the ability of each system to met a nitrogen loss restriction.

A linear programming model and a simulation model were integrated in this analysis. A simulation model was used to develop a nitrogen loss coefficient. Daily haul system was compared to five typical systems; dry stack, earthen pit, earthen pit with irrigation, lagoon and lagoon with irrigation. The income effects of adding the

five systems were compared to the daily haul. It was assumed that waste system would differ in their ability to met nitrogen loss reductions because of timing and crop utilization of nitrogen. Partial budgeting was used to develop coefficients for two farm sizes. Information needed the partial budgeting came from survey and extension specialist.

Earthen pit with irrigation increased income as compared to the daily haul system for the 60 cow dairy. Earthen pit with irrigation, lagoon and lagoon with irrigation increased income for the 100 cow dairy. This increase in income as compared to daily haul can be attributed to better timing and utilization of nitrogen fertilizer and labor savings with the irrigation systems. A marginal cost curve of reducing the amount of allowable nitrogen loss was developed for each system. The 100 cow dairy could best meet the nitrogen loss constraint with the daily haul system. While the earthen pit with irrigation was better able to meet the nitrogen loss constraint.

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CHAPTER I

INTRODUCTION

Proper management of animal waste has become a major concern for Tennessee dairy farmers. In the past, animal waste was viewed as a valuable by-product of livestock production and was the main source of plant nutrients. Then as cheap chemical fertilizers became available, animal waste was seen only as a nuisance. Recently however, greater environmental awareness has resulted in placing greater value on proper management of animal waste.

Today, agriculture is seen as a major contributor to non-point source pollution. Dairy farmers have become concerned about the possibility of restrictions or regulations that might affect their dairies economically. Some states have implemented regulations limiting runoff from dairy farms by requiring immediate incorporation of waste or restricting farmers from spreading manure during winter months when the ground is frozen or snow-covered. Other restrictions include limitations on the total manure applied per acre and on the number of dairy cows allowed per acre of farmland (Good, Connor, Hoglund, Johnson, 1974).

Presently, agricultural policy is influenced by health concerns over safe water. People are not willing to take risks with water quality standards. Nitrate associated with agricultural practices is a major water quality consideration. Dairy farms have been cited as major contributor to water quality because of animal waste and heavy nitrogen fertilizer use.

Many outside the agricultural community are concerned that voluntary control of non-point source pollution will not be effective. They argue that society has an obligation to develop new policies that redefine the rules and alter farmers' rights (Batie, 1988). Many non-agriculturalists see mandatory regulation as the only way to make additional improvements in water quality.

BACKGROUND

Water Quality Legislation

Beginning in the 1970's, agriculture was identified as a major source of pollution. The most far-reaching legislation came with Public Law 92-500, Federal Water Pollution Control Act Amendment of 1972. The objective of the law was to restore the chemical, physical, and biological integrity of the nation's waters. Goals were set to eliminate discharge of any pollutants into navigable waters by 1985 (USDA 1979). The 1972 law required operators of municipal facilities, feedlots (including dairy farms), and industries to obtain a permit which specifies the amount and type of pollutants allowed. The federal government delegated the responsibility of developing a plan for water quality management, including both point and non-point source pollution to the states. The 1972 law established that any dairy over 700 cows must apply for a permit. The law was later amended to restrict feedlots of any size from discharging waste water into navigable waters, except for runoff resulting from more than a 10-year, 24-hour storm. This criteria was revised in 1983, allowing no discharge of runoff or waste water from feedlots, except for runoff resulting from more than a 25-year, 24-hour storm (USDA, 1979).

Non-point source pollution (NPS) enters the environment from diffuse sources unlike point-source pollution. Contaminants from NPS generally cannot be monitored at the point of origin, and the exact source is difficult to identify. One of the more complex issues in water quality involves nitrogen in the form of nitrates. Much debate has occurred over the role of agriculture in contributing to increased levels of nitrates in groundwater.

The U.S. Geological Survey has identified 1,437 counties, about 46 percent of the counties in the U.S., as areas of potential contamination from pesticide and fertilizer use. All of these counties were intensively farmed, with 33 percent of all land in these counties in cropland, compared to only 16 percent of the nation's land in crops (Bouwer, 1990).

NITRATES AND AGRICULTURE

All forms of nitrogen do not have the same potential for water degradation. Nitrogen in the soil is usually organically bound in humus as NH_4 or NO_3 (Porter, 1975). Nitrates (NO_3) have a high potential for leaching into groundwater and are the most common form of water soluble nitrogen in soils. Chemical fertilizers contain nitrogen in a form readily absorbed by plants not easily moved through soil, thus reducing the potential for leaching into groundwater. Nitrogen can be transported from soils by rain, runoff, and leaching. Many factors influence the amount of nitrogen reaching water, such as climate, soil, topography, management, and land use. Most nitrogen in surface runoff is organic nitrogen associated with eroded soil. In most croplands, nitrate leaching below the root zone ends up in groundwater (Schaller and Bailey, 1983). Nitrate contamination of ground water is more likely if the underlying material allows rapid water movement. Thus, very deep water tables are more likely to be contaminated than those at more moderate depths.

Nitrogen Cycle

The process of transforming nitrogen from various organic and inorganic forms is commonly called the nitrogen cycle (Figure 1). Immobilization occurs when inorganic nitrogen is assimilated by plants and microorganisms to form organic nitrogen compounds containing NH_3. Mineralization is the decomposition of organic nitrogen into NH_4, and the conversion of NH_4 into NO_3 and NO_2. Denitrification is the reduction of NO_3 and NO_2 into NO_2 and N_2. At this time, the process of immobilization is repeated when the inorganic nitrogen is reduced by nitrogen fixation into NH_3. These biological reactions are accompanied by the chemical reaction of ammonia volatilization, which is the release of NH_3 from soil and plants into the atmosphere (Schaller and Bailey, 1983).

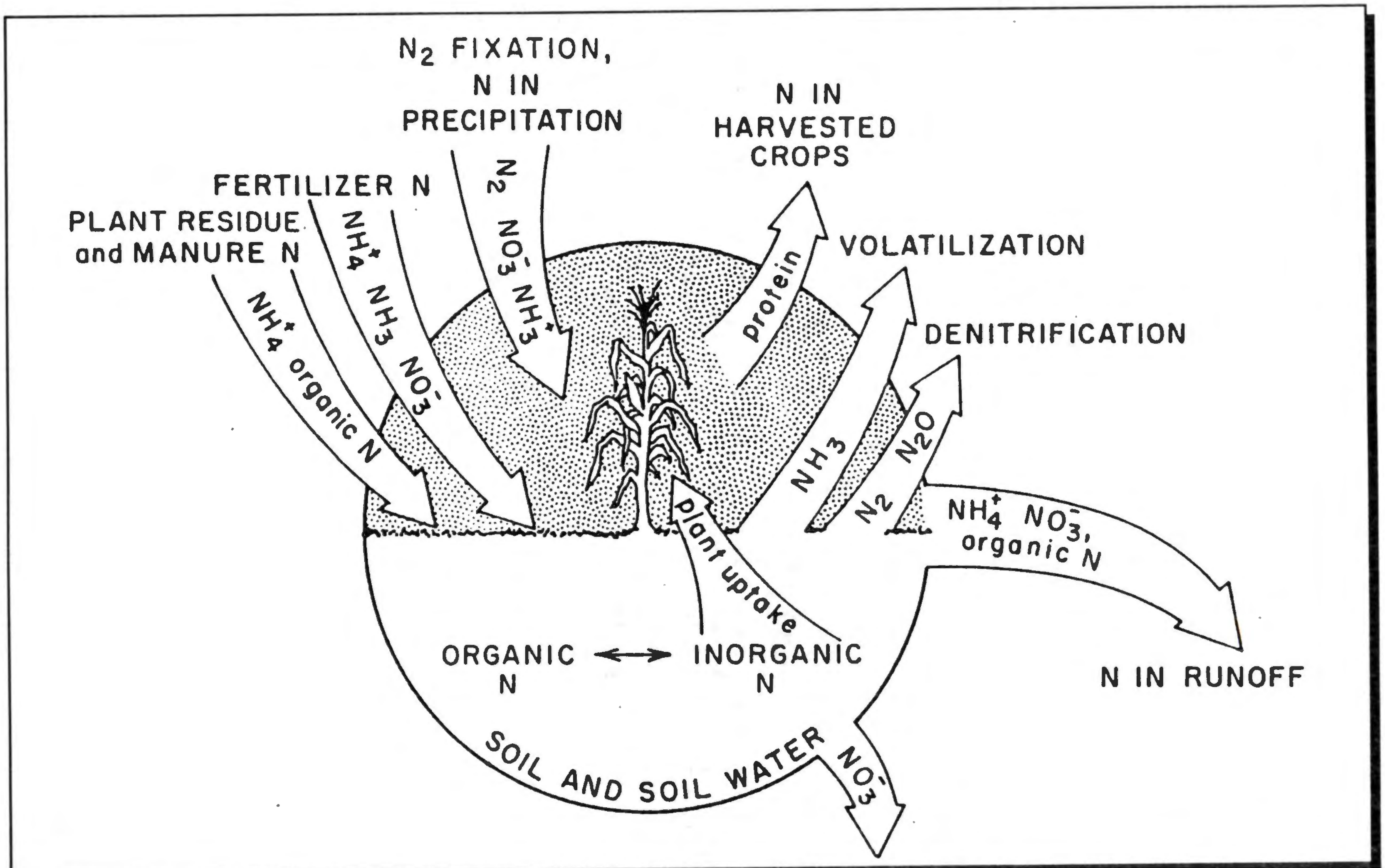

Figure 1. Nitrogen Cycle

Source: Porter Keith, 1975

Agricultural Links to Nitrates

The Big Spring Basin study is one example demonstrating a link between agricultural activity and increased nitrates. The study found nitrate levels in the groundwater to be less than 1 milligram per liter in the 1930's. Concentration of nitrates rose to 3 milligrams per liter by 1960 and to 10 milligrams per liter by 1983. Land in the Big Spring Ground Water Basin is in agricultural uses, with the main sources of nitrogen in the watershed manure and fertilizer. Nitrogen fertilizer application increased almost three-fold over the period of study. Increases in nitrate concentration in the groundwater seems to be related to increased use of nitrogen fertilizer (Hallberg, 1986).

Other studies comparing pasture grassland areas and intensively farmed lands, found that intense farming resulted in nitrate concentrations from 5 to over 100 milligrams per liter, while pasture lands had less than 2 milligrams per liter (Kilmer, et al., 1974), (Schuman, Burwell, Piest, Spomer, 1973).

Other studies have shown a direct link between fertilization rates and NO_3 leaching. Baker and Johnson (1981) showed a direct relationship between nitrate leaching and fertilizer application in field plots. They also found that the level of leaching is affected by rainfall, soil type, and the level of the water table.

Not until recently has any research been aimed specifically at estimating losses of nitrogen fertilizer to leaching. Meanwhile, recommended application rates for nitrogen fertilizer are usually based on maximum yields. At these high rates of application, nitrogen recovery by most crops is only around 50 percent (Hallberg, 1986).

Health Effects

Groundwater pollution is a potentially serious health problem since over 40 million people in the U.S. use wells as their primary source of water (Bouwer, 1990). The first observations of nitrates in drinking water were made in 1945 (Cantor, 1988). Since then adverse health effects, such as birth defects, infertility, Parkinson's Disease, and methemoglobinemia have been associated with high nitrates in groundwater. High nitrate levels are especially dangerous to infants (National Academy of Science, 1987). Other health effects of nitrates are not as clear. Nitrate compounds with a large number of secondary amines can form n-nitrosoamine, which are among the most active carcinogens known in animals. However, little evidence exists to link them to cancer in humans (Cantor ,1988).

The EPA has established the maximum allowable level of nitrates in drinking water at 10 mg/liter (Tennessee Department of Public Health, 1989). These guidelines were developed according to the potential health risk to humans. Ten mg/liter was chosen as the limit for nitrate levels in groundwater on the basis of epidemiological evidence that indicates no cases of methemoglobinemia have been reported in areas where water contains nitrates at less than 10 mg/liter (Walton, 1951).

Best Management Practices

Due to the uncertainty and complexity of agricultural activities, the approach most often employed for the reduction of nitrate contamination has been that of Best Management Practices (BMPs). "BMPs are practices that can be used to control nonpoint source pollution and that are socially and economically acceptable" (Baker and Johnson, 1981). The term Best Management Practices (BMPs) was introduced in the Federal Water Pollution Control Act of 1972 (PC 92-500) as a concept to deal with the unique problems associated with nonpoint source pollution. The goal of BMPs is to address nonpoint source pollution in a voluntary manner compatible with existing practices. BMPs involving structures have usually been accompanied by some level of cost sharing by government, based on the idea that the farm should not bear the total cost of environmental quality improvement.

BMPs to control agricultural waste usually include some type of control of runoff from concentrated livestock areas and the incorporation of manure immediately after spreading. For example, due to the potential NO_3 loss from winter spreading of manure, a waste storage structure is considered a Best Management Practice (Albers, 1990), (Holloway, Bottcher, Nordstedt, 1990). Thus far, BMPs have been criticized for their lack of effectiveness. In order for BMPs to be effective, they must first be adopted by the farm operator. BMPs have not been significantly implemented at the watershed level without a high level of cost sharing (Logan, 1990). Dairy farmers are concerned with the economic effects of implementing animal waste BMPs.

Current Water Quality Policy

Current water policy impacting the agricultural sector is framed by two sometimes conflicting government agencies, the USDA and the EPA. The USDA favors a voluntary approach, by which farmers are encouraged to adopt management practices which reduce potential water degradation. The EPA, on the other hand, generally favors regulations as defined in the Safe Drinking Water Act (PL93-523) and the Clean Water Act (PL92-500) (Reichelderfer, 1980). Under this approach, each state has been delegated responsibility for developing their own water quality plans. Each state has the option of choosing any of those policies that they feel will work best in their area, based on local situations and variations in the nonpoint source pollution problems.

Many non-agricultural groups are calling for a more regulatory approach to water quality concerns. Under this approach, the farmer would be required to purchase and maintain certain structures or change management practices to fit a subscribed set of regulations. This mandatory approach would reduce the farmer's right to choose the type and amount of inputs required to meet production goals. Good (1972) reported that several states had enacted control measures on animal waste, including limits on winter spreading and on total allowable manure spread per acre. Ashraf and Christensen (1974) found 26 states had water quality laws applicable to waste management. Further regulations and restrictions on the dairy farm are a real possibility.

Dairy Farms

Dairy farmers have been singled out in particular as potential nonpoint source polluters for several reasons. Dairy farms in East Tennessee have followed the national trend towards fewer farms and larger numbers of cows per farm. Due to this concentration of dairy cows, the quantity of waste each farm must handle has increased. In addition, the practice of utilizing pasture for parts of the year has given way to confinement on concrete for most of the day (Morgan, 1987). In fact, larger dairy farms seldom utilize pasture at all. Increased confinement time results in greater need for manure handling practices.

PROBLEM STATEMENT

Nonpoint source pollution associated with animal waste is usually traced to land application sites. Loss of nitrates from land receiving manure is a concern both from a production as well as a water quality perspective, when farmers apply additional fertilizer to compensate for nitrogen leached from the soil.

Presently, less than thirty percent of Tennessee dairy farmers have a waste storage system (Montgomery and Hooper, 1992). A waste storage system would be expected to improve water quality through lower nutrient losses. However, imposing a waste storage requirement may alter cropping patterns and reduce farm sizes.

This study will examine the cost of imposing a waste storage requirement for dairy farmers by examining effects on farm income. Six waste management systems are incorporated into a farm system. The NO_3 field losses from each waste system are analyzed. The economic costs and nitrogen reduction costs from each waste management systems are compared to the base farm, daily haul.

RESEARCH PURPOSES AND OBJECTIVES

The purpose of this study is to compare the economic and environmental analyses of the six dairy waste management systems. The dairy waste management systems will be compared for herd sizes of 60, and 100 head.

Numerous combinations of collection, storage, and spreading equipment sizes could be considered. However, many of these systems are rarely practiced by Tennessee farmers. Analyzing all possible combinations would create an large number of systems with only slight variations. Therefore, six waste management systems representative of those currently employed by Tennessee dairy farms will be analyzed.

Specific objectives of the study are:

1. To develop a linear programming computer model of a dairy farm, including various waste management systems;
2. To determine the economic effects of various waste management systems on farm income for different farm sizes; and
3. To compare economic cost of reducing nitrogen loss from each waste management systems.

Summary of Procedures

Many studies have taken a partial budgeting approach in viewing each waste management system as a separate enterprise. Coote (1976), however, states that "the dairy farm is a complex system of interacting components or processes, and decisions related to feed purchases, crop selection, herd size, fertilizer application, building modifications, and manure handling must be evaluated for their effect on the total system". Therefore, a "whole farm" approach will be used in this study. In addition, the development of nonpoint source pollution simulation models makes it possible to add an environmental component to this whole farm analysis.

Data used in this study were taken from a survey of dairy farms conducted on the Big Limestone watershed in July and August, 1991. Two types of models were used, simulation and linear programming. The simulation model was used to obtain environmental coefficients, and the linear programming model was used to maximize farm income within the environmental constraints of imposing a waste management system, and restricting NO_3 losses from the farm. Partial budgeting was used to develop coefficients for the waste management systems, cropping systems, and livestock production activities.

CHAPTER 2

LITERATURE REVIEW

Management of dairy waste is seen as an increasingly important component of livestock production. Recent heightened emphasis is primarily a result of greater environmental concern for potential water quality degradation. Five different analytical approaches and objectives have been employed in dairy waste management studies: partial budgeting, least cost, imposed environmental regulations, nutrient balance, simulation models.

Partial Budgets

Partial budgeting compares various waste systems based on the initial investment cost and annual operating cost. These studies typically do not consider possible variations in labor requirements or environmental effects, though some have attempted to use indices for environmental effects.

In 1987, Morgan used a partial budget approach to describe and analyze the six most common waste management systems used on Tennessee dairy farms. An economic evaluation of the various systems was made on the basis of investment cost, and annual cost. The six systems evaluated in this study were (1) daily haul, (2) dry stack, (3) earthen pit, (4) above-ground tank, (5) single-stage lagoon, and (6) two-stage lagoon. These systems were compared for 80-, 160-, and 320-cow herd, and for two confinement systems.

Evaluation of the three herd sizes, two confinement systems, and six waste handling systems produced seventy-eight distinct management systems. Budgets were developed for (1) collection of manure, (2) storage, (3) application, (4) nutrient mineralization, (5) annual labor and energy costs, (6) initial investments, (7) capital recovery and insurance, repair, and housing costs, and (8) net annual cost.

Based on net annual cost, daily haul was found to be the least costly handling system, and above-ground steel tank was the most expensive. Net annual costs were also compared for each herd size and confinement system. Daily haul with partial confinement was the most economical system, followed by earthen pits, and then by dry stack. Morgan (1987) stated "No one type of dairy waste management system exhibits a clear cost advantage over all herd sizes." Morgan (1987) also found installing greater storage capacity on specific systems was not economical, as systems with lower capital requirements usually had higher labor requirements. Net annual cost per cow ranged from $10 to $53 for systems with no storage and from $15 to $200 for systems with storage.

Morgan (1987) noted that each farm has a unique set of resources, which should be considered when selecting a manure system. He concluded that "a dairy operator should choose a manure handling system that can be operated easily by farm workers, meet regulations, may be adapted to existing farm structures, retain nutrient content of the waste, as well as minimize costs."

Moore (1982) used the partial budgeting approach to compare six waste management systems in Oregon: (1) dry stack, (2) earthen pit, (3) daily spread, (4) above-ground tank, (5) lagoon flush, and (6) lagoon flush with separator. The systems were compared for herd sizes of 100, 200, and 300 cows. For the daily spread, a 75-day storage tank was assumed for liquids. The above-ground tank had storage capacity of 150 days, and the lagoon system had a 1-year storage capacity. Moore (1982) used a capital recovery approach to estimate annual cost.

Moore (1982) found earthen storage to have the lowest initial cost, followed by daily spread, while the above-ground tank was the most expensive. Earthen pits and lagoon flush had the lowest annual cost. The earthen storage system did have the highest energy and labor costs. The study also showed cost decreases on a per cow basis as herd size increased from 100 to 300 cows. Moore (1982) stated that pollution control considerations should be included along with cost in selecting a waste management system. Storage structures allow the dairy operator more flexibility in applying manure and minimizing run-off. Thus, daily haul has the highest pollution potential due to lack of storage. Moore did not assign a level of management to the various systems, though it is an important aspect of waste management system selection.

Henderson (1972) used the partial budgeting approach in comparing and analyzing four typical waste management systems in Tennessee: (1) anaerobic lagoons, (2) liquid pit, (3) irrigation, and (4) conventional (daily haul). According to Henderson (1972) anaerobic lagoons used for cattle manure should have one cubic foot of water for each pound of cow with a 14-foot minimum depth. Lagoons require proper management to maintain water levels and to prevent runoff. A liquid pit is simply a "dug pond" with enough water added for proper agitation but not enough to increase amount hauled. Its size of the liquid pit is a function of herd size and days of storage. The liquid pit allows for flexibility in spreading, an advantage when weather conditions or labor constraints exist.

Conventional, or daily haul, is still the most common manure handling system, according to Henderson. Its big disadvantage is the inflexibility of tractor and labor requirements. The farmer must haul even under less than ideal weather and field conditions. The irrigation system is just an extension of the pit or lagoon. Henderson (1972) used the same value of manure for each system, $16.05 per cow per year. Investment costs and annual costs were compared for herd sizes of 40, 50, 75, 100, 150, 200, 250, 300, 350, and 400 cows. Henderson found that lagoons had the lowest initial cost for herds up to 100 cows. Irrigation had the highest original cost, but required the least labor for all the systems. Henderson (1972) recommended lagoons for most herd sizes, based on cost and labor requirements. Irrigation presented some advantages for larger herd sizes.

In an EPA report, White and Forster (1978) evaluated alternative waste management systems for various livestock species in the U.S. They included consideration of temperature, rainfall, topography, and various livestock systems present in different regions of the country. Environmental cost/benefit analyses were prepared for each separate species. Manure fertilizer values were included in the benefits and considered at two levels of return, 50 percent and 100 percent, assuming that not all crops would be able to utilize all available nutrients from manure. Cost of manure was based on fertilizer price equivalents. Type of housing was cited as a major factor in determining type of manure storage.

The study ranked waste management systems on net annual costs and improvements in air and water quality. Each system was evaluated on an air and water pollution scale one to five, with one being no pollution. The study noted that water pollution problems were usually small. However, runoff problems occurred when manure was not incorporated into soil soon after spreading. Soil incorporation was noted to improve air and water quality as well as net returns. Free stall housing increased pollution more than the manure handling systems themselves. Yet, improvements in water and air quality were small in comparison to the cost of runoff control for free stall housing systems.

Holik and Lessley (1982) developed partial budgets using data obtained from a survey in Maryland. Daily spread was used by 96 percent of farms with less than 100 cows and by 78 percent of farms with 100-199 cows. The survey results showed that use of manure storage increased as herd size increased, ranging from 4 percent of farms of less than 100 cows, to 80 percent of farms with the largest herd sizes. Holik and Lessley (1982) evaluated 11 different systems. Herd sizes of 75, 150, cows were selected as representative of the study area. Labor requirements were dependent upon herd size and handling system used.

Earthen storage systems had the lowest investment cost as compared to other systems. Results of the study also indicated that annual cost per cow was inversely related to herd size. Total manure value over all systems ranged from $58 to $62.

Least Cost Studies

Some studies use linear programming techniques to determine the least cost manure management system by choosing among many alternative components of a manure management system. These studies separate the waste management system into collection, handling, and spreading.

Ogilvie, Phillips, and Lievers (1975) used a technique called Critical Path Method (CRPM) to choose among 100 least cost systems with alternative components. They recognized three distinct stages of manure handling systems: (1) collection, (2) storage, and (3) spreading. Evaluation took into account herd sizes and various sizes of spreading equipment.

An economy of scale effect was recorded for each system. Differences in housing cost were mainly due to type of bedding and choice of storage facilities. Variable costs for liquid systems were only 50-70 percent of the costs for other systems, but they had higher fixed costs. Labor cost was assumed constant and no benefits of improved labor distribution were recognized. Nor was credit given for nutrients in the manure. The cost of purchasing larger spreading equipment was shown to be justified, even for small herd sizes.

Burney, Lo, and Carson (1980) analyzed a network of dairy management components based on capital investment, annual cost, labor, and energy requirements. Manure storage structures included (1) roofed and open concrete tanks, (2) above and below ground tanks, (3) slatted floor barns, (4) earthen lagoons, and (5) stacking slabs. Manure was assigned a negative value. The herd was housed during winter periods of 180 days, and the distance from the storage facility to the field was set at .3 kilometers.

A comparison between irrigation and spreader tanks found irrigation was beneficial only in labor savings. The study noted the network approach was sensitive to input parameters used, i.e. if equipment size, storage costs, or spreading distance were changed, the relationship between subsystems would probably be altered.

Nutrient Balance Studies

Nutrient balance studies evaluate how different manure handling systems can supply various amounts of nutrients. Most of the studies compare different manure incorporation times with the amount of nitrogen supplied.

Storehouse and Narayanan (1984) analyzed the contribution of livestock manure to the supply of plant nutrients. The study's objective was to compare costs of supplying crops with plant nutrients from two alternative sources: (1) chemical fertilizer, and (2) livestock manure supplemented with chemical fertilizer when needed. The study used a linear programming technique to evaluate alternative manure handling systems. The linear programming model was first run simulating the existing farm situation. The model objective function was set to minimize cost of supplying plant nutrients. Alternatives consisted of six main groups: (1) manure handled as a solid separately from liquid handling, (2) liquid manure, (3) manure handled as solids but runoff handled as liquids, (4) off-farm manure disposal and sales, (5) chemical fertilizer application, and (6) custom hired field distribution. Nitrogen was the balancing nutrient due to the relatively high cost of nitrogen fertilizer. The study also accounted for on-farm energy consumption by manure handling and fertilizing activities.

Results showed that increased efficiency could be achieved by changing the method of spreading manure, and immediately incorporating it. These two changes reduced costs of purchased nitrogen from $1,820 to $795. However, these changes did increase the cost of labor, tractor use, and energy from $7,020 to $8,495. The authors concluded that if commercial fertilizer costs rise as they did in the 1970's, opportunity cost of manure would rise proportionately. Yet, the crops receiving manure could provide only a third of the nutrients needed to sustain livestock. Therefore, the possible level of self-sufficiency is limited.

Safley, Haith, and Price (1977) developed a linear programming model to select a manure handling system for a 100-cow dairy operation. Fertilizer value of manure was included in the model and daily haul was selected as the optimal manure handling system for the simulated farm.

A second model was developed to choose a manure handling method based on a whole farm system with several assumptions. Manure could only be spread on certain crops during given time periods. A nitrogen budget was constructed for the model and the amount of nitrogen required for each crop was predetermined. The researchers noted this was an oversimplified soil nitrogen budget, with assumptions that all nitrogen in manure is available for crop use and that equal percentages of manure and fertilizer nitrogen are used by the crop. Soluble nitrogen and phosphorous runoff losses were calculated as the product of estimated runoff and nutrient concentration. The researchers assumed that phosphorous was not affected by manure or fertilizer application and that potassium was not a pollutant. The study found no addition nitrogen would need to be purchased. Results of the study indicated that no additional nitrogen would need to be purchased, since all nitrogen could be obtained from manure. The cost of manure handling did not affect the cropping practices but did reduce net income.

Environmental Regulations Studies

Other studies included some environmental regulations for dairy farmers, stemming from the 1972 Federal Water Pollution Control Act Amendment. Partial budgeting and linear programming are again the primary tools selected. In a 1972 study, Jacobs and Casler used a partial budgeting approach and incorporated environmental variables. The study analyzed three components of waste management systems: (1) collection, (2) storage, and (3) disposal. Herd sizes of 50 and 100 cows were used for stanchion barns, and 50-, 100-, and 200-cow herds were used for free stall barns. Annual costs were a function of housing type, manure handling equipment, type of storage equipment, length of storage, and herd size. Total annual cost consisted of storage and equipment costs plus labor, electricity, and tractor costs.

Results of the study showed an annual cost of $40 per cow with a daily haul spreading system for a 100-cow herd in stanchion or free stall barns. A stacking manure system increased the cost to around $50 per cow, and liquid storage systems cost between $65 and $70 per head.

The study included potential environmental impact effects by consulting a group of experts who scored each system for impacts on odor, water, and air pollution. Results indicated cost and environmental impact scores tended to have an inverse relationship. The authors went on to suggest that these cost and environmental scores could be further analyzed through linear programming to find the least cost system, given a set of environmental constraints.

In 1982, Heimlich utilized a linear programming approach to analyze various herd size adjustments in response to a phosphorous loss restraint. The linear programming model was run for 35-, 54-, and 116-cow herds typical to Vermont. The linear programming model incorporated herd management, replacement heifers, feeding, and milk production. Feeds were translated into nutrient equivalents, and milk production was directly related to feeding requirements through a milk response function. Twelve different manure management systems were included in the model. Phosphorous losses were a function of soil erosion and manure spreading. Heimlich (1982) ran a base solution for each farm, then reduced phosphorous losses by 10 percent from the base level. Results of the study indicated that certain levels of phosphorous loss could be reduced by shifting manure spreading among crops and among seasons. However, at higher levels of restriction, all manure was stored and spread in the spring or fall. Phosphorous loss was directly dependent upon reducing soil erosion. A 19.3 percent decrease in net income accompanied a 50 percent decrease in phosphorous losses for the small farm in this study. Large and medium size farms lost 8.9 percent and 10.6 percent respectively, with the same reduction in phosphorous losses. Heimlich noted that non-monetary benefits from water quality improvement could not be directly incorporated into benefit calculations.

Coote, Haith, and Zwerman (1976) used a linear programming approach to analyze the relationship between optimal economic management practices and losses in nitrogen, soil, and phosphorous.

> "The farm's available land resources will exert a profound influence on all management practices. Crop rotations are dictated by land capability, animal nutrient requirements, and efficiency of nutrient utilization. The many activities on the farm compete for labor, capital, and land resources." (Coote, Haith, and Zwerman, 1976)

The linear programming model consisted of three parts: (1) a model of the dairy farm, (2) equations to determine nutrient balance on the farm, and (3) equations to estimate environmental impact of farm management practices selected by the model. Potential nutrient losses were computed as differences between the amount of nutrients applied from manure and fertilizer and the amount used by crops. Runoff, as determined by the model, was the concentration of soluble nitrogen in runoff water from soil under idle land conditions. The soluble nitrogen loss was runoff from a particular soil and crop. The enrichment ratio was the ratio of soil nitrogen levels under cropped conditions to those under idle conditions. The authors assumed the value of nitrogen in manure to be constant at five Kg/ton, and that 35 percent of ammonia nitrogen was lost for each time period. Coote, et al. (1976) listed several limitations for this model and for linear programming. They noted that estimates of nutrient losses based on the assumptions above were inexact. Other limitations are estimates for environmental losses, assumption of linear cost for each farm activity, restrictions on time period, and quality of input data.

Haith and Atkinson (1977) simplified an earlier linear programming model developed by Coote. The model recognized the farm as a complex system of interacting components. Pollutant losses were included and limitations placed on crop land, manure spread, soil, and crop mixtures. Herd size was constrained to a maximum number, and was further limited by the amount of nutrients which could be supplied by the farm. A nitrogen balance was also estimated for the model, allowing for mineralization and denitrification losses in nitrogen content of manure. The study assumed all manure nitrogen was available for the crop with no distinction made between chemical and manure fertilizer. Environmental parameters were estimated by the model for potential nitrogen loss, i.e. the difference between applied nitrogen and that used by a particular crop. The authors noted that the model may have overestimated the nitrogen losses through runoff, and that the model also failed to account for 5,800 Kg of the total 9,893 Kg of nitrogen. Thus, they concluded that some portion of nitrogen may have leached into groundwater. The model also included the option of placing a new manure system on the whole farm operation.

Haith and Atkinson (1977) concluded that the model has potential for analyzing the impact of changes in farm management, such as changes in manure storage systems, on various environmental restrictions imposed upon the farm. The model was run on two "representative" farms for various herd sizes. The farm with the highest income also had the lowest soil, sediment, nitrogen and phosphorous losses. On the second farm, income-maximizing practices had an adverse environmental impact, mainly due to soil erosion.

Schaffer, Jacobs, and Casler (1975) used linear programming to model the trade-off between farm profit and environmental water quality for the watershed level. The total amount of nitrogen, soil, and phosphorous losses were known for the entire watershed. Total nutrient and soil losses were divided by the sum of the computed losses from all watershed activities. This proportion was used as the delivery ratio to modify all preliminary cropping loss coefficients. Then these nutrient loss coefficients were imported into a linear programming model. Comparisons were made between dairy manure spreading and storage with immediate manure incorporation. The researchers found that storage of manure actually increased nitrogen loss. Adding manure storage to watershed farms also reduced farm income by fifteen percent. The study concluded that added cost of manure storage was not justified.

Good, Connor, Hoglund, and Johnson (1974) analyzed the economic impacts of specific pollution control measures on dairy farms. Specific areas evaluated were investments, labor requirements, milk production costs, and return to operator labor and management. Control measures evaluated were (1) probation of winter spreading, (2) control of surface runoff, and (3) immediate subsurface disposal of manure. The researchers utilized a linear programming and partial budgeting approach to analyze certain waste management systems used in Northern States. They considered two types of housing, stanchion and enclosed housing and herd sizes of 40-, 60-, 80-, and 160-cows. Six separate manure systems were analyzed in the study.

Housing type strongly influenced cost of manure handling systems. Additional mandatory controls on runoff cost $48.43 per cow in the 80-cow herd, and $34.53 per cow in the 100 cow herd. However, for the 80-cow herd, runoff controls added six percent in net returns to operator labor and management. The authors noted that degree of water degradation from winter spread of waste depended on slope of land, type of vegetation, soil type, nearness to a body of water, application rate, and timing of waste disposal. Restriction on winter disposal could substantially affect farmers, since most dairy farms have no storage facilities. Including a six-month solid storage system would add $200 per cow for stanchion barns and $112-$120 for open lot and cold curved systems. This runoff restriction reduced returns to operator labor and management by twenty three percent and fifteen percent for 40 and 60 cow herds in stanchion barns. Reduction in returns ranged between 8.7 percent and 6.6 percent for 80 and 160-cow herds on open lots.

Johnson, Hoglund, and Buxton (1973) evaluated the possible effects of environmental controls on dairy farmers. Johnson, et al. (1985) states: "Controls external to the market system have been developed to provide for a more socially desirable balance between environmental degradation and production activities. The cost of producing milk will be affected by such non-market controls." A 1971 survey of certain dairy states found most states have control provisions that would affect dairy production facilities and dairy waste control systems. Thus, the study included a linear programming model which analyzed the impacts of various environmental constraints placed on dairy farms. Results indicated that implementing these constraints would require adjustments in the manure handling systems on many farms. Cost would depend on herd size, type of housing, and manure system selected, and on-site runoff would depend on housing and site-specific factors.

Ashraf and Christensen (1974) used a linear programming model to analyze two manure handling systems for 25 representative farms, with herds of 50, 100, and 212 cows. Various manure spreader sizes and lag periods for manure in the soil were analyzed. Income reduction due to installment of a manure system was related to the size of the manure handling equipment. Results of the study indicate that value of the manure gained by soil incorporation did not pay for the additional labor cost. Ashraf and Christensen (1974) suggest that the comparatively low cost involved may be high enough to force small, marginal farms out of business. They noted, "Manure disposal systems designed to abate water pollution also require intensified use of labor during spring and fall and thus aggravate the work load of these periods." Thus, the amount of land growing corn was reduced due to the competition for labor between corn silage and manure disposal. Plowing under of manure was found to be the most significant factor in changing the crop mix for each farm size.

Simulation Models and Linear Programming

Recently, simulation models have allowed researchers to incorporate nitrogen loss and financial variables into a linear programming model. This has increased the validity of nitrogen loss coefficients for the models.

In 1991, Allen, et al. dealt with financial effects of installing waste systems on larger farms in Texas. Dairy herds of 300 and 720 cows were chosen as representative farms in Texas. The researchers modelled economic, financial, and management decisions over a five-year period using the Farm Level Income and Policy Simulator (FLIPSIM).

The added cost of waste management systems for the 300- cow herd reduced the chance of survival for the farm from 89 percent to 31 percent. For the 720-cow herd, chances of survival dropped from 99 percent to 86 percent for the farm. If milk production or milk prices fell 13 percent, chances of survival dropped to 0.

Young, Crowder, Shortle, and Alwang (1985) used a two-stage modelling approach to measure various conservation and manure management practices. Estimates of field-level losses of soil and nutrients were first estimated with the CREAMS model. CREAMS is a computer simulation model that compares field losses of pollutants among different management practices. Part of the CREAMS results were incorporated into a representative farm linear programming model designed to evaluate alternative manure storage and handling systems.

Results of the study show very little difference between nitrogen loss from manure daily spreading and six-month storage. However, the model did not account for direct runoff losses from the barnyard, which may be higher for daily spread. The study noted nutrient savings would almost offset the cost of the storage structure for a typical 45-cow dairy farm. However, a storage structure could not pay for itself on large farms with excessive amounts of manure, because the crops could not utilize all the conserved nutrients. Nutrient losses were reduced by about ten percent without affecting net farm returns, but additional reductions were prohibitively expensive. Young, et al. (1985) noted that use of field Best Management Practices (BMPs) could reduce nutrient losses but not in proportion to soil losses. In fact, solving soil erosion problems could aggravate nutrient losses.

Johnson, Adams, and Perry (1991) conducted a study of on-farm costs of reducing water pollution. Management practices, crop yields, and groundwater pollution were assessed by combining plant simulation, with hydrologic and economic models of farm level processes. The researchers analyzed possible adjustments to management practices and income in order to reduce nitrate leaching. They used CERES, a plant simulation model, to predict crop yields under different fertilization rates. An optimization model was used to find reductions in irrigation and fertilization. Finally, a linear programming model was employed to analyze various crop mixes for the representative farm. The three models were linked by using output from CERES model as input for the dynamic optimization model. The output from the optimization model was placed in a whole farm framework in the linear programming model.

The study noted that farmers could eliminate nitrate leaching by better management of fertilization schedules. They compared current practices with the effects of 25 percent reductions in nitrogen application, nitrogen input taxes, and pollution taxes. They found that a 50 percent reduction in nitrogen leaching can be achieved by reducing nitrogen and water applications to corn, without any changes in crop mix. Conversely, taxation had little effect on the crop rotations.

Crowder, Pionke, Epp, and Young (1985) developed a representative dairy farm using a mathematical model, CREAMS, to estimate chemical and erosion runoff. The coefficients obtained were imported into an economic linear programming model to analyze the trade-off between income and reductions in soil and chemical losses. The study did not distinguish between surface and groundwater contamination by NO_3 losses from the farm.

The linear programming model was made up of 4 main components: (1) crop production practices, with alternatives for crops grown, tillage practices and rotations, (2) crop harvest and storage activities, (3) crop utilization and dairy production activities, and (4) farm sales and purchases. Environmental coefficients were developed using CREAMS, and constraints were imposed on total losses of soil, nitrogen, and phosphorous. Only surface runoff losses of nitrogen were constrained to 15.7 Kg/ha/year, due to difficulties of modelling the nitrogen cycle. Results of the determining base nitrate losses, the allowable nitrate loss was reduced by increments of 10 percent to evaluate the effect on each waste management systems.

It has been suggested that a waste storage system would allow farmers to better time manure application to crop needs, thus reducing the NO_3 losses from the fields (Holloway, Bottcher, Nordstedt, 1991). Other studies have found that actual field runoff may be increased by adding a manure storage system (Young, et al. 1985).

The second constraint used in this study was a limitation on the total NO_3 loss allowed from a given farm. Young, et al. (1985) found that a 10 percent reduction in nutrient losses would have very little impact on net farm returns, however additional reductions had a substantial impact upon net farm income.

STUDY AREA

The Big Limestone Watershed, located in Washington and Greene Counties in Northeastern Tennessee, was chosen for this study because it had a high potential for nonpoint source pollution. The 735 farms in the watershed of 50,690 acres, average sixty-six acres per farm. The area has a high concentration of dairy farms, many of which are located less than 500 feet from streams, (see Figure 2). Agriculture is the primary industry in the watershed, and livestock accounts for sixty-three percent of agricultural sales. Seventy-eight percent of the farms have less than $10,000 in sales (Census of Agriculture, 1987).

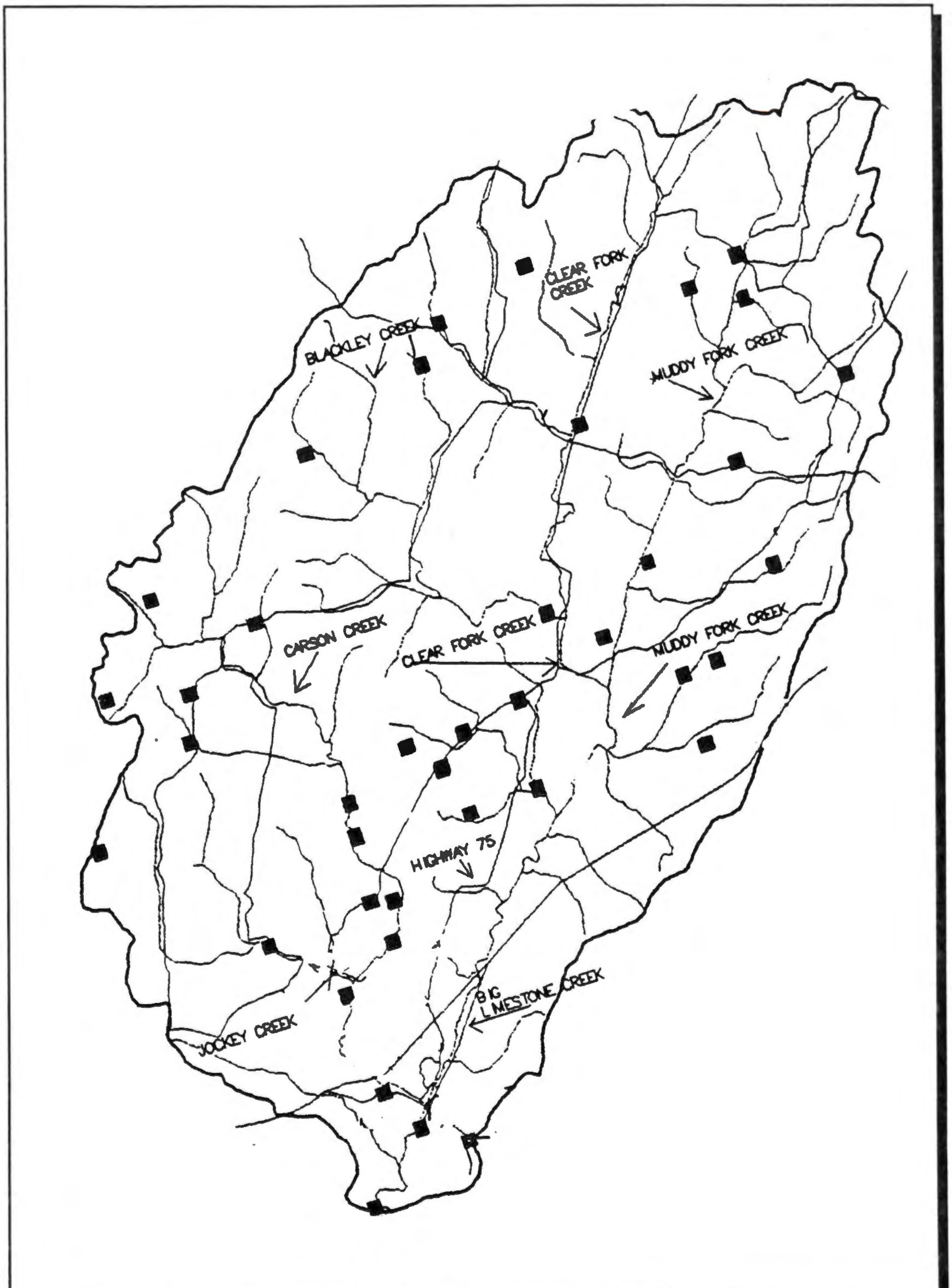

Figure 2. Location of Dairy Farms on the Big Limestone Watershed

Source: Preliminary SCS report on Big Limestone Watershed project, 1991.

The area is characterized by gently rolling hills and valleys. Sinkhole and depressions are common, with an erratic surface drainage pattern. Average annual precipitation of 44.39 inches is distributed throughout the year. Mean temperature is 56.6 degrees. Main soils are Dunmore and Pace, with Dunmore making up the largest area. Dunmore soil is deep and well-drained, having a clayey subsoil, with moderate to moderately slow permeability and moderate to high available water holding capacity. Pace makes up a very small portion of this soil association. The soil is well suited for most crop production. The gently sloped land is suited for row crops, and the steeper slopes are moderately suited for hay, pasture, and woodland (USDA, 1957).

The watershed has been identified as containing agricultural contaminants. The SCS and other government agencies have suggested that these contaminants are mainly from livestock enterprises without adequate waste management systems. Animal waste was identified as a major contributor to surface water quality degradation. Although limited data on groundwater quality were available, the existence of numerous sinkholes increases the potential for groundwater contamination from animal waste (USDA, 1991).

SURVEY PROCEDURES

In the summer of 1991, 106 farm operators on the Big Limestone were surveyed through personal interview. The survey asked detailed questions on resource endowments, tillage and crop production practices, and contact with government agencies (See Appendix A).

After consulting U.T. Statistician, Dr. Sanders, a random area approach was chosen. A county highway map of the study area, with the watershed boundaries drawn in, was overlaid with a grid. Grid size was designed to give an average of 5 farms per square. Each square was assigned a random number. A list of randomly drawn numbers was then used to select squares for study. A dot was placed in the center of each square, and only those squares in which the dot fell inside the watershed boundaries were counted. In addition, only squares containing roads were counted. Twenty squares were selected by this method, and all farm operators within those squares were surveyed.

Enumerators from the Tennessee Statistical Service were contacted to conduct the personal interviews. Only farm operators who made at least $1000 from the farm were interviewed. Using these criteria, 106 interviews were conducted, including fifteen dairy farms. Information obtained from these fifteen dairy farms was used to develop two representative dairy farms for the linear programming model.

Survey Results

The average dairy farm size was 281 acres, with an average herd size of sixty six cows, producing an average of 16,300 pounds of milk per cow per year. Survey results did not indicate that herd size was related to milk production levels. The majority of the dairy farms have free-stall housing and a herringbone milk parlor, with Holsteins being the most common breed in the area. Average equipment value was $106,169, and average annual gross sales was $205,391. Thirty-two percent of the dairy farmers worked off the farm. Dairy farms had an average of thirty percent cropland. Average crop acreage and yields are presented in Table 3.1.

Table 3.1 Crop Production Practices on The Big Limestone Watershed

Crop	Average Acres	Average Yield	Average Fertilizer			Tillage Practices (Percent Usage)			
			Nitrogen	Phosphorus	Potassium	Mold-board Plow	Chisel Plow	Disk	No-Till
			....	(pounds)	....				
Pasture	80		48	42	42				
Corn	43	93	113	92	101	29	14	14	43
Corn Silage	73	18	113	92	101	14	43	14	29
Rye		4	39	30	30	0	0	100	0
Wheat	35	5	57	57	57	0	0	50	50
Fescue Hay	79	3	49	55	55	0	67	33	0
Alfalfa	16	3	61	85	120	0	0	0	0

Source: Big Limestone Watershed Survey, 1991

WASTE MANAGEMENT SYSTEMS

After consulting with extension water quality specialist Tim Burcham, six waste management systems were selected as typical for Tennessee. All systems were assumed to be plausible for either of the two representative farms. However, the topography of some locations could be prohibitive for earthen pits and lagoons. The average distance from the manure system to the field was set at 1,000 feet. House and feeding lots were assumed to be 100 ft^2/cow (Morgan, 1987).

Daily Haul

Daily haul was the most common waste management system in the watershed consisting of a tractor and loader, a box spreader, and a tractor for hauling. Manure is hauled at least weekly, allowing for inclement weather and peak labor constraint interruptions.

Dry Stack

The dry stack consists of a four-month roofed storage building and a holding pond for runoff and seepage. A tractor loader, a solid spreader, and a liquid spreader are also used in this system. The system storage capacity was calculated as [(daily waste per animal * confinement time) + (.5 * lbs. daily bedding/density of bedding)] * number of animal units * number of days of storage (Morgan, 1987). Storage time was from November to February.

Earthen Pit /Liquid Spreader

The earthen pit system uses a tractor for scraping, a box scraper, a liquid tank spreader, a tractor for spreading, and a tractor for agitation and loading of stored waste. Earthen pit sizes are calculated by the amount of waste collected, amount of precipitation on housing lot, precipitation on the storage facility. Storage period is from October to March.

Anaerobic Lagoon/Liquid Spreader

The anaerobic lagoon waste system consists of an agitation pump, tractor for spreading, liquid spreader, and a six-month storage structure. Storage is assumed to be for six months, October to March, with two "dewaterings" a year. The total lagoon size is made up of the minimum design volume, waste storage volume, dilution volume, "25-year, 24-hour storm runoff" and a free board.

Earthen Pit/Irrigation

One variation on the earthen pit is to alter the method of waste disposal. This may prove practical for larger dairies, where labor constraints may prevent use of liquid tankers. A traveling big gun and irrigation pump were substituted for the liquid tank spreader. All other equipment components remained the same.

Single Stage Lagoon/Irrigation

The single stage lagoon method of waste disposal was combined with a traveling big gun. All other equipment components remained the same as the lagoon.

LINEAR PROGRAMMING MODELS

Linear programming was chosen as a extension of budgeting procedures because it facilitates the evaluation of a large number of alternatives and allows the consideration of approximations to real world constraints, such as limits on the evaluation of land, labor, and other resources. Linear programming is a widely accepted method of allocating limited resources among competing enterprises in the most efficient way (Hillier and Lieberman, 1986).

Linear programming models are made up of decision variables and resources (j), and the objective function's purpose is to maximize the activity's value, given constraints on the resources. The objective function could be written as $Z = f(X_1,X_2,X_n...)$, where Z is the function to be maximized and X represents the activities. The general form of the model is:

(1) $$Z = \sum_{j=1}^{n} C_j X_j$$

In this equation, C_j are the values per unit of output, X_j are the activities and n is the number of activities. The objective function is restricted by the availability of various resources to accomplish the activities. The constraints are expressed as:

(2) $$\sum_{j=1}^{n} a_{ij}, x_j \leq b_i$$

In this equation, a_{ij} is the quantity of the i^{th} resource required in the production of one unit of the j^{th} activity. Resource restrictions are represented by b_i's, with n being the number of constraints. The linear programming model is a series of similar equations meeting the requirements of each activity within the confines of each constraint.

These equations are then solved simultaneously. The mathematical model would be expressed as:

$$\text{Maximize } Z = c_1x_1 + c_2x_2 + \ldots + c_nx_n$$

Subject to:

$$\begin{array}{l} a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n \leq b_1 \\ a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n \leq b_2 \\ \quad \vdots \qquad \vdots \qquad\qquad \vdots \\ a_{m1}x_1 + a_{m2}x_2 + \ldots + a_{mn}x_n \leq b_m \end{array}$$

Linear Programming in Agriculture

Coote, Haith, and Zwerman, (1976) discussed the advantages of linear programming in Modelling the Environmental and Economic Effects of Dairy Waste Management. Linear programming allows for quick evaluation of many alternative farm management decisions. Combinations of practices can be selected which optimally meet both economic and environmental objectives. Linear Programming allows for a unified means of problem solving, analyzing available data and selecting an economical design or management program for accomplishing the objectives. Linear programming has been widely used in evaluating many types of agricultural problems (Agraval and Heady, 1972), (Heady and Vocke, 1979), (Safley, Haith, and Price, 1977), (Ashraf and Christenson, 1974), (English, 1977), and (White and Parthenheimer, 1980).

Limitations of Linear Programming

Linear programming includes several assumptions which may lead to limitations:

1. The effects of a single variable or activity are proportional.
2. The interactions among variables must be additive.
3. The variables must be continuous, i.e. fractional values must be allowed for the decision variables.
4. The parameters of the model are assumed to be known constants.
5. Evaluates what should be rather than what is.

NO_3 Loss Simulator

NO_3 losses can be affected by type of manure handling system, timing of application, and amount of manure/fertilizer applied. Previous studies included linear programming models to simulate nitrogen loss, but their success was limited (Coote, 1976). A mathematical model was needed to determine the amount of NO_3 loss for various farm management decisions. Numerous nutrient leaching models are available that have been discussed in the literature, including DRASTIC (Allen, 1985), Cerres-Maize (Jones and Kinery, 1986), SOYGROW (Wilkinson, Jones, Boote and Mishoe, 1985), CREAMS (Crowder, Peonke, Epp, Young, 1985), and EPIC (Putman, Dyke, 1987).

DeCoursey suggests several considerations when selecting a model. Farm planning studies should utilize a model that can show the relative advantage of farm management practices rather than one that shows absolute values. Some models are scaled specifically for field, farm, or river basin levels. The time period is also very important in selecting an appropriate model for a study. With these considerations in mind, the Erosion-Productivity Impact Calculation (EPIC) was selected as the mathematical model to provide the NO_3 loss coefficients.

EPIC was originally developed to determine the relationship between soil erosion and soil productivity for the 1985 RCA appraisal (Williams, Renard, and Dyke, 1983). The model was designed to be physically based and capable of simulating the simultaneous processes of erosion and nutrient losses given available inputs. EPIC can be applied over many soil types, climates, and crops in the United States. Various effects of management changes can be analyzed. EPIC simulates daily runoff, erosion, plant growth, harvest, and weather, and then computes daily balances as inputs for the next day. The EPIC model is derived by a stochastic series of daily weather events and initiates a chain reaction and a daily change in the values of various physical and chemical processes. Management and technology are static in the EPIC model and cannot be varied during the simulation. EPIC is composed of a series of submodels which simulate weather, hydrology, sheet and rill erosion, plant nutrient, plant growth, management, soil tillage, and plant environment at the farm level. Each of the submodels is linked to all the other submodels. A schematic drawing of EPIC with the submodels is illustrated in Figure 3.

Weather parameters needed for the operation of EPIC include precipitation, air, temperature, solar radiation, and wind. The soil erosion submodel uses the

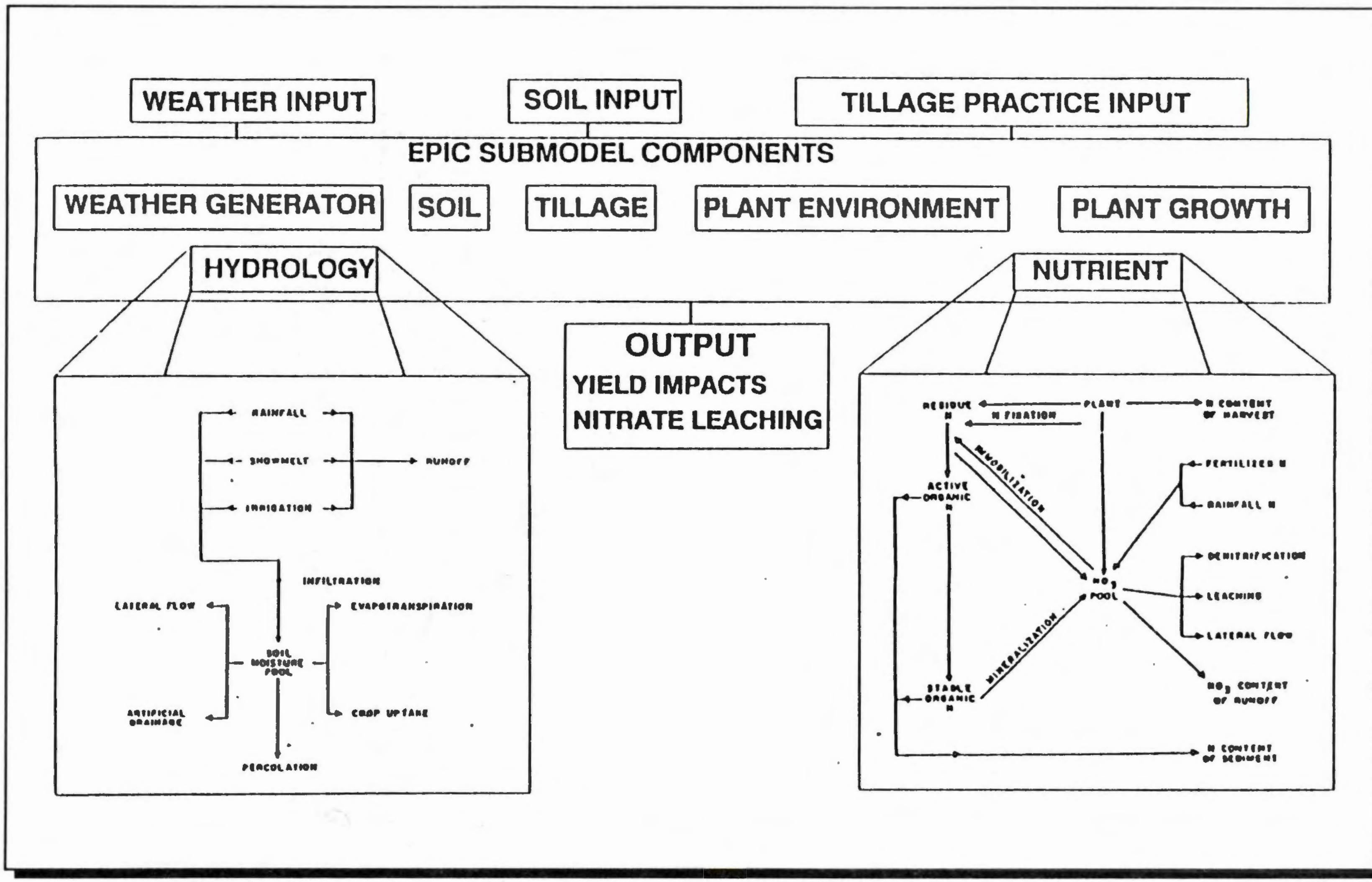

Figure 3. EPIC Input, Output and Submodel Components

Source: Gary Cole, 1991

universal soil loss equation (USLE) and the Omstad-Foster equation in computing soil erosion each day. The volume and peak discharge rate of surface runoff is simulated in the hydrology submodel given daily weather and irrigation events. Soil moisture is estimated from infiltration, percolation, lateral subsurface flow, drainage, evaporation, irrigation, and snow melt. Nitrogen processes estimated include rainfall nitrogen, mineralization, denitrification, nitrogen fixation, fertilization, immobilization, leaching of NO_3, upward NO_3 movement by soil water evaporation, crop uptake, organic N transported by sediment, and NO_3 runoff.

The plant growth submodel simulates energy interception, energy conversion to roots, above-ground biomass, moisture and nutrient uptake, and root, grain, and fiber production. Corn, wheat, grain sorghum, soybeans, cotton, peanuts, alfalfa, grasses, oats, and barley have been developed with specific parameters to simulate growth. The plant growth is constrained by water, nutrient, and temperature stresses.

EPIC's soil submodel has up to 10 soil layers with soil-specific properties incorporated into the database. These properties include thickness of layer, bulk density, water holding capacity, minimum field capacity, wilting point, inorganic N, NO_3, labile P, crop residue, sum of the bases, inorganic C, $CACO_3$, coefficient of linear extension, pH, KCl attracted, aluminum content, percent sand, silt, clay, and freezing points, and coefficients of linear extensibility.

Crop rotations and crop budgets can be specified in the tillage and management submodels. Crop rotations can be anywhere from one continuous crop up to a maximum of 6 crops. Once simulation has begun, however, the crop rotation cannot be changed. Crop budgets allow choices in the implements used and preferred dates for each operation. Four alternative harvest options may be specified in tillage and management submodels.

The plant environmental control submodel includes irrigation, fertilization, lime, and pesticide functions. This section also specifies an insect, weed, and disease loss function. EPIC utilizes these submodels to simulate natural processes and interactions among climate, land, and agriculture. EPIC measures changes in output values based on input, consumption, and management alternatives. The model may be used to estimate different management options with the same soil and climate (Putman, Dyke ,1987), (Cole, 1991). EPIC has been used in 150 locations over a wide variety of situations and has proven to be a valuable tool for project level planning and research (Williams, 1983).

The EPIC model was used to provide information on NO_3 losses from various waste management systems in this study. The NO_3 loss coefficients were developed by simulating each farm with each waste management system.

Limitations of EPIC Model

EPIC measures runoff at a field level, but the model is unable to estimate runoff from the barnlot, which may vary with different systems. For this study, all barnlot runoff was assumed to be diverted or controlled, and all NO_3 loss was assumed to occur after manure was spread on the field.

DESCRIPTION OF THE LINEAR PROGRAMMING MODEL

The linear programming model utilized in this study is made up of three sections. The first section is the dairy farm production decision variables. This section is composed of seven different crops grown on three different land classifications. The seven crops grown on the representative farms were pasture, corn, corn silage/rye, corn silage/wheat, fescue hay, corn silage, and alfalfa. Pasture, corn silage, wheat, and rye were grown to meet nutrient requirements of cows and heifers. Hay, alfalfa, and corn could either be fed to livestock or bought and sold off the farm, whichever optimized the nutrient supply to the livestock. Labor was supplied by the family or purchased in six two-month periods. Labor was considered to be a major constraint on the farm.

Six different manure handling systems make up the second section. The base model was run with a daily haul system, which is typical for East Tennessee dairy farms. The cost of adding each of the other five waste storage systems were then compared to the daily haul system. Five systems typically found in Tennessee were chosen for comparison: (1) four-month dry stack, (2) six-month earthen pit, (3) six-month earthen pit with travelling big gun, (4) six-month anaerobic lagoon, and (5) six-month anaerobic lagoon with travelling big gun. This section allows for different time periods during which manure is available for spreading. Each system has different labor requirements during different time periods. Therefore, a system might require additional labor during peak labor demand periods for crop activities. Each system conserved a different amount of nitrogen that could be used as a substitute for commercial fertilizer.

The third section is describes the timing of manure disposal in six different time periods. Crop nutrient requirements could be met by either manure from the system or commercial fertilizer. The NO_3 losses were estimated from this section of the model with the assumption that different amounts were lost in different time periods. Each manure handling system could only supply manure during certain time periods, and this section linked the system supply with cropland needs during the six time periods of January/February, March/April, May/June, July/August, September/October, and November/December. In addition, the effects of each manure storage system on the cropping patterns and nutrient requirements of each dairy farm were analyzed.

The model was designed to show changes in relative farm level income, not actual levels of net income. Factors that were constant in all simulations, such as depreciation, interest, taxes, and value of family labor, were eliminated from the study. Costs that were different for each of the waste systems were compared on an annual basis.

THE MATHEMATICAL MODEL

The linear programming model used in this study maximizes net returns subject to resource limiting, input purchasing and output selling constraints. The objective function is specified such that costs of production excluding land, family labor, nitrogen fertilizer and managerial charges is subtracted from the income from selling livestock and crop products. The theoretical objective function would be specified as Net Revenue = Price * Quantity - Cost. The objective function can be specified as:

Maximize NR such that

$$
\begin{aligned}
NR = &+ \sum_{k=1}^{5} SLA_k * XSL_k + \sum_{m=1}^{3} SCA_m * XCA_m - \sum_{i=1}^{2} CLP_i * XLA_i \\
&- \sum_{j=1}^{12} CCP_j * XCA_j - \sum_{r=1}^{2} CRL_r * XRLT_r - \sum_{n=1}^{4} (BCA_n * XBC_n) \\
&- BHA * XHB - CLB * XHL - CMS * XMS - \sum_{o=1}^{12} (CNA_o * XFB_o)
\end{aligned} \tag{3}
$$

i = 1,2 for the two livestock types (1 = cow, and 2 = heifer).

j = 1-12 for the 12 crop enterprises (1 = pasture 1, 2 = pasture 2, 3 = pasture 3, 4 = corn, 5 = corn silage/rye, 6 = corn silage/wheat, 7 = corn silage, 8 = hay 1, 9 = hay 2, 10 = hay 3, 11 = alfalfa 1, 12 = alfalfa 2).

m = 1-3 for the three crop products that can be sold (1 = alfalfa, 2 = hay, 3 = corn).

k = 1-5 for the four livestock products that can be sold (1 = milk, 2 = replacement heifers, 3 = cull cows, 4 = bull calves, 5 = heifer calves).

n = 1-4 for the four livestock feeds that can be bought (1 = corn, 2 = concentrates, 3 = hay, 4 = alfalfa).

o = 1-12 is the 12-crop nitrogen fertilizer activity (units are in pounds of nitrogen).

r = 1-3 for the land types (1 = 8 percent slope, 2 = 14 percent slope, 3 = 22 percent slope), (units are in acres).

Where:

CLP_i is the cost of livestock production type (i) (units are dollars per cow or heifer);

CCP_j is the cost of crop production (j) (dollars per acre);

SCA_m is the price of crop product sold (m) (dollars per bushel or ton);

SLA_k is the price of livestock product sold (k) activity (dollars per cwt or per head);

BCA_n is the price of feed buy activity (n) (dollars per bushel or ton);

BHA is the replacement heifer buy activity (dollars per heifer);

CLB is the price of purchased labor (dollars per hour);

CMS is the annual cost of a manure system (dollars per system);

CNA_o is the price of nitrogen purchased for crop activity (o) (cents per pound);

CRL_r is the price of rented land types (r) (acres);

XLA_i is the activity level of livestock (i) (1 head of livestock);

XCA_j is the activity level of crop production (j) (acres);

XSC_m is the activity level of crop selling (m) (bushels or tons);

XBC_n is the activity level of feed buying (n) (bushels or tons);

XSL_k is the activity level of selling livestock products (k) (cwt or per head);

XHB is the activity level of buying replacement heifers (per heifer);

XHL is the activity level of buying labor (hours);

$XRLT_r$ is the activity level of renting land type (r) (acres);

XFB_o is the activity level of buying nitrogen fertilizer to meet crop requirements (o) (pounds of nitrogen fertilizer);

XMS is the activity level of single manure system; and the other variables have been previously defined.

The objective function is subject to several input and output constraints. The land constraints retrains the model as land quality types are limited for a given farm operator. Other input constraints require the purchase of labor, nitrogen fertilizer, replacement heifers at predetermined prices. The output constraints allow for the selling of livestock and crop products. Other constraints require the nitrogen produced by the livestock enterprises to be used by the crop activities. The constraints are expressed below.

Land Constraint

There are two constraints that restrict that the amount of land available to the producer. The first constraint reflects land quality requirements and the amount of land used in a cropping system less than land rented to less than or equal to the amount of land owned. The equation is reflected in equation as:

$$(4) \qquad \sum_{j=1}^{12} QL_{r,j}*XCA_{r,j} - XRL_r \leq RLT_r$$

Where:

QL is the quantity of land required for production of crop activity (j) on land type (r) (acres);

XRL_r is the amount of rented land of each land type (r) (acres);

RLT_r is the amount of land available for each land type (r) (acres); and the other variables have been previously defined.

The second constraints restricts the producer ability to rent land. The producer can rent land quality types one and two. The constraint is:

$$(5) \qquad QRLT_r * XRLT_r \leq RRL_r$$

Where:

$QRLT_r$ is the amount rented land of land type (r) (acres);

RRl_r is maximum amount of land type (r) that can be rented (acres)

$XRLT_r$ is the activity level of renting land type (r) (acres); and the other variables have been previously defined.

Labor Constraint

Labor constraint reflects the livestock, crop and manure system labor requirements. Labor can be supplied by the family or purchased at five dollars per hour. There was not any limit placed purchased labor. The constraint can be expressed as:

$$(6)\quad \sum_{i=1}^{2} LLR_{p,i} * XLA_{p,i} + \sum_{j=1}^{12} (CLR_{p,j} * XCA_{p,j}) + MLR_p - XHL_p \leq RFL_p$$

p = 1-6 for the six two-month time periods (1 = January and February, 2 = March and April, 3 = May and June, 4 = July and August, 5 = September and October, 6 = November and December).

Where:

$LLR_{p,i}$ is the labor requirements for livestock activity (i) in time period (p) (hours);

$CLR_{p,j}$ is the labor requirements for crop activity (j) in time period (p) (hours);

MLR_p is the labor requirements for the waste management system in time period (p) (hours);

RFL_p is amount of family labor available in each time period (p) (hours); and the other variables have been previously defined.

Nitrogen Balance

There are four constraints that restrict the nitrogen availability. The first constraint was nitrogen available from the waste storage system to be spread on the crop activities in the six time periods. The amount of manure from the livestock activities was transferred to the waste storage system. The crop nitrogen requirement were met first by the manure then the remainder was met by purchased fertilizer. The amount of nitrogen loss was restricted for each of the waste management systems.

Nitrogen availability

Each waste management system could supply different amount of nitrogen in different time periods. Due to the mineralization process some percentage of nitrogen is not available to the crop in the year of application. However, nitrogen not available was assumed to be balanced nitrogen mineralized from previous applications.

(7) $$- QNO_p * XMS_p + \sum_{j=1}^{12} QNS_{p,j} * MD_{p,j} = RNTS_p$$

Where:

QNO_p is the amount of nitrogen available in time period (p) from the waste management system (pounds of nitrogen);

$QNS_{p,j}$ is the amount of nitrogen in manure available from the waste management system in time period (p) for crop activity (j) (pounds of nitrogen);

$MD_{p,j}$ is the amount of manure disposed on crop activity (j) in time period (p) (pounds);

$RNTS_p$ is the transfer row for nitrogen from waste management system to crop activity in time period (p) (pounds); and the other variables have been previously defined.

Manure production constraint

The manure constraint is the amount of manure produce by the livestock and transferred to the waste storage system. Each cow was assumed to weigh 1400 pounds, and producing 115 pounds of manure per day. Heifers average weight was 500 pounds producing 41 pounds of manure per day. Total manure collected was assumed to be a factor of the number of cows, percent time confined, and number of days in the period. Time the cows spent on paved lots was 12 hours per day. Heifers were confined for six hours per day.

$$(8) \qquad \sum_{i=1}^{2} (- QMA_{p,i} * XLA_{p,i}) + QMA_p * XMS_p = RMT_p$$

Where:

RMT_p is the manure transfer row of manure from livestock activity to waste management system in time period (p) (pounds);

$QMA_{p,i}$ is the quantity of manure produced by livestock activity (i) in time period (p) (pounds); and the other variables have been previously defined.

Nitrogen fertilizer constraint

The nitrogen fertilizer constraint requires the amount of nitrogen required for the crop activities to be met first by the nitrogen from the manure system then purchase any additional nitrogen required by the crop enterprises. This constraint links availability of manure for disposal from each manure system with the availability of land for disposal.

$$(9)\quad \sum_{j=1}^{12} (-QNR_{s,j} * XCA_{s,j} + \sum_{p=1}^{6} (QNS_{p,s,j} * XMD))_{p,s,j} \sum_{o=1}^{12} -(QNA_{s,o} * XFB_{s,o}) = 0_s$$

s = 1-7 for the seven crop production activities nitrogen requirements (1 = pasture, 2 = corn, 3 = corn silage/rye, 4 = corn silage/wheat, 5 = corn silage, 6 = hay, 7 = alfalfa);

Where:

$QNR_{s,j}$ is the quantity of nitrogen required by crop (s) on crop activity (j) (pounds of nitrogen fertilizer);

$QTS_{p,s,j}$ is the quantity of nitrogen supplied by waste disposal system in time period (p) for crop (s) on crop activity (j) (pounds of nitrogen);

$QNA_{s,o}$ is the amount fertilizer bought for crop activity (s) by fertilizer buy activity (o) (pounds);

$XFB_{s,o}$ is the activity level of purchasing nitrogen fertilizer for crop activity (s) by fertilizer buy activity (o) (pounds); and the other variables have been previously defined.

Nitrogen loss constraint

Each waste management system apply different amount of nitrogen in different time periods. Since crop activities were better able to use the nitrogen in certain time periods than others contributed to different nitrogen loss from different systems. The ability of each waste system to supply nitrogen in the time period where the crops can best use it is reflected in this constraint.

$$(10) \qquad \sum_{p=1}^{6} \sum_{s=1}^{7} QNL_{p,s} * MD_{p,s} \leq RNO3$$

Where:

$QNL_{p,s}$ is the amount of nitrogen loss from crop activity(s) in time period (p);

RNO3 is the maximum amount of nitrogen loss allowable from a dairy farm (pounds of nitrogen loss from surface, subsurface and leached);

MD is the manure disposal activity on crop activity (j) in time period (p) (pounds of nitrogen); and the other variables have been previously defined.

Livestock Constraints

There are four livestock production constraints. The milk sell constraint requires the amount sold to be less than or equal the amount produced. Replacement heifer constraint requires the number of heifer produced by the cows plus the purchased and raised to be less than or equal to amount need to maintain a certain herd size. Two other constraints cull cows and dairy cow maintain the herd size at certain number. A twenty five percent culling rate was assumed for the model. The dairy cow number were fixed at 60 or 100 cow herds.

Milk sell constraint

The milk sell constraint requires the amount sold to be less than the amount produced. The equation can be written as:

$$\text{(11)} \qquad \sum_{i=1}^{2} (- QMK_i * XLA_i) + XSL_k \leq 0$$

Where:

QMK is the amount of milk produced per cow in one year (cwt);

XSL_k is the activity level of selling livestock product (k) (cwt or head); and the other variables have been previously defined.

Replacement heifer constraint

The replacement heifer constraint requires the number of heifers produced by the cow minus a five percent death loss plus heifers purchased to be less than or equal to the number of heifer need to maintain a certain herd number. A twenty five percent culling rate was assumed for the model. A 90 percent calf crop is assumed, with 50 percent heifers, 50 percent bulls.

$$(12) \qquad \sum_{i=1}^{2} - QRH_i * XLA_i + BHA_k + XSL_k \leq RHFC$$

Where:

QRH_i is the number of replacement heifers that are produced be dairy cows (1 heifer);

RRCH is replacement heifer requirement needed to maintain the herd size (per head);

BHA_k is replacement heifer buy activity (k) (dollars per heifer); and the other variables have been previously defined.

Dairy cow constraint

The dairy herd numbers were fixed at 60 or 100 head. Much of the farm structure such as milking parlor, equipment were designed for a fixed number. The waste management systems require certain equipment and storage sizes. The size is a function of the number of cows and time spent on lot. The equation can be written as:

(12) $$\sum_{i=1}^{2} QCC_i * XLA_i = RCOC$$

Where:

QCC_i is the number of cow (i) (1 cow);

RCOC is the number of cow required for a given farm (cow); and the other variables have been previously defined.

Cull cow constraint

The cull cow constraint requires the number of cow sold to less than or equal to culling rate of twenty five percent of the cow herd. A one percent death loss was assumed for the cows. The equation can be written as:

(14) $$\sum_{i=1}^{2} (- QCC_{i\ ,k} * XLA_i) + XSL_k \le 0$$

Where:

QCW_i is the number of cows culled each year (cow); and the other variables have been previously defined.

Feed Requirement Constraints

There are two type of feed constraints. Protein constraint requires the amount of crude protein for cows and heifers to be less than or equal to the of amount of crude protein from the feed conversion or purchased concentrate. Net energy constraint requires the amount of net energy to be less than or equal to the amount of net energy from the feed conversion and purchased concentrate.

Protein constraint

The protein constraint requires the livestock protein requirements are met by the crop enterprises or purchased feed. The feed conversion variable changes crop product to units of protein.

$$(15) \qquad \sum_{i=1}^{2} (QPR_i * PLA_i) - \sum_{f=1}^{8} (QPS_f * FC_f) - XBC_2 \leq 0$$

f = 1-8 for the seven animal feeds that can be converted to net energy and protein (1=hay, 2=alfalfa, 3=corn silage, 4=rye, 5=wheat, 6=pasture, 7=corn, 8=concentrate)

Where:

QPR_i is the amount of crude protein required by livestock activity (i) (pounds of protein);

QPS_f is the amount of crude protein available from feed conversion (f) (pounds of crude protein per unit of animal feed); and the other variables have been previously defined.

Net energy constraint

The net energy constraint required a bushel or ton of feed to be converted to pounds of net energy. The net energy requirements of the livestock must be less than or equal to the amount of net energy supplied for the crop activities or purchased feed.

$$(16) \qquad \sum_{i=1}^{2} (QNE_i * PLA_i) - \sum_{f=1}^{8} (QNES_f * FC_f) - XBC_2 \leq 0$$

Where:

QNE_i is the amount of net energy required by livestock activity (i) (MCAL);

$QNES_f$ is the amount of net energy available from feed conversion (f) (MCAL per unit of animal feed); and the other variables have been previously defined.

Crop Production Constraint

The crop production constraints requires the amount sold to be less than the amount produced minus the amount used by the dairy herd. All crops are converted to net energy and protein for the livestock activity.

(17) $$\sum_{j=1}^{12}(-QY_{j'm} * XCA_m)-XBC_n+FC_f \leq 0$$

Where:

FC_f is the conversion of one unit of animal feed (f), produced on an acre of land or purchased, to crude protein and net energy (tons or bushels);

QY_j is the yield for each crop activity (j) (bushels or tons); and the other variables have been previously defined.

Concentrate Constraint

The concentrate constraint limits the amount of concentrate that can be purchased to 2.5 ton per to reflect the normal feeding practices of the watershed.

(18) $$QCB*XCN \leq RCOT$$

Where:

QCN is the amount of concentrate required for one cow for one year (tons);

XCB is the quantity of concentrate bought in one year (tons); RCOT is the concentrate transfer row (tons); and the other variables have been previously defined.

DEVELOPMENT RESOURCES OF CONSTRAINTS

Capital

No limit was placed on capital available to the farm. Net returns used in the model were estimated as returns above variable expenses. No capital charge was made for family labor or land. The only capital included in the model was the annual cost of production and annualized cost of each manure system. Annual capital requirements for the six manure handling systems were calculated by the following formula (Morgan, 1987), (Moore, 1982), and (Johnson, 1991):

AD + Insurance, Repairs, Taxes + FLC + Labor = Annual Cost

The following formula was used to obtain the depreciation values for the manure systems.

(19)
$$AD = \frac{V_a - V_s}{EL}$$

Where
- AD = annual depreciation
- V_a = value in dollars when acquired
- V_s = value when salvaged
- EL = expected life

Fuel and energy costs (FLC) were computed by the following formula:

$$FLC = \frac{\text{PTO hp X Load factor X price/gal.}}{K}$$

K = 11.2 for diesel engines

Insurance, repairs, and taxes were calculated at 1.25 percent of initial investment cost. Labor hours were calculated for each activity associated with the waste management system. The labor formulas are presented in Appendix B.

The annual cost of each waste management system is presented in Appendix C.

Land Resources

Three land groups were created for the representative farms. Slope is the limiting factor for soils in the area. Dunmore soil makes up ninety-five percent of the land area, and can be divided into two slope categories. The 8 percent slope is suitable for crop production. The 14 percent slope is suitable only for alfalfa and hay production. The remainder is 22 percent slope and is suitable for pasture and hay production (Table 3.2).

Table 3.2 Soil Type Acreage for Representative Farm

Soil	Slope	Percent of Land	Total Acreage Farmed	Acreage Rented	Acreage Owned
	.... percent	......	....	acres	....
60 Cows					
Dunmore	8	30	75	62	13
Dunmore	14	40	99	82	17
Dunmore	22	30	75		75
Totals			**249**	**144**	**105**
100 Cows					
Dunmore	8	30	104	78	26
Dunmore	14	40	138	103	35
Dunmore	22	30	104		104
Totals			**346**	**181**	**165**

Source: USDA, 1957

Labor Availability

Labor requirements for the crop and livestock enterprises were obtained from the Tennessee Farm Planning Manual. Both labor requirements and availability were obtained in two-month intervals. Besides family labor, additional labor was purchased at $5.00 per hour. Hired labor was assumed to be available as needed. Labor requirements for the six manure storage systems were adapted from a study by Moore (1982), Morgan (1987), and Ashraf and Christensen (1974). The labor requirements for each system were unique to each farm. Labor required for each task was determined by such factors as topography, distance from storage facility to nearest field, and size of equipment. Equations have been developed to compute labor requirements for each waste management system (Morgan, 1987). These equations are presented in Appendix B. The specific tasks involved are dairy cleaning, agitate and transfer, agitate and load, and hauling. Labor supply is represented in Table 3.4.

Table 3.4 Labor Supply in Hours for Representative Farms

	J/F	M/A	M/J	J/A	S/O	N/D	Total
Operator	450	450	550	500	525	525	3,000
Spouse	60	60	45	45	60	60	330
Child	-	-	40	80	-	-	120
Child	-	-	40	80	-	-	120
Total Family Labor	**510**	**510**	**675**	**705**	**585**	**585**	**3570**

Source: Johnson, 1990

NO_3 Loss Constraint and Coefficients

EPIC was used to generate NO_3 losses for each crop rotation in each of the six time periods. A leaching ratio loss for each period was obtained by dividing the amount of nitrogen lost in a particular time period by the amount applied. A similar approach using an enrichment ratio was used by a study by Haith and Atkinson (1977), and Coote et al. (1976) Haith and Atkinson (1977) developed an enrichment ratio by subtracting the amount of manure and fertilizer applied from the amount used by the crop. Nitrate losses are different in different time periods due in part to different crop requirements for fertilizer or manure at certain times. For example, there would be less nitrates lost in period two (March-April) because of greater crop utilization. In periods one (January-February) and six (November-December) most of the nitrates would be lost because of lower crop utilization. EPIC estimates the nitrogen losses from surface, subsurface, and leaching for each crop in each time period. The model first allows the crop to obtain the nitrogen requirement from the manure applied. If the nitrogen requirements cannot be met, nitrogen fertilizer will be purchased.

The nitrogen loss constraint was developed by taking the total amount of nitrogen (organic and inorganic) applied in a certain time period to each crop and each land type, and multiplying it by the nitrate loss ratio, to give the total nitrogen lost from each farm and waste handling system. The nitrogen loss constraint was reduced in increments of 10 percent for each farm size with each the six systems.

Nitrogen Availability

Nitrogen availability varies between storage systems, method of application, and length of time between incorporation and application. Ranges in the rate of nutrient loss during storage for each of the six systems are presented in Appendix C. The mid-point was used for these loss ratio ranges. Nitrogen loss in manure for each system was subtracted out when calculating the fertilizer value used in annual cost budgets for each system. The losses also vary for each method of manure application. These losses from the storage system and field application method were incorporated into the linear programming model. Nitrogen is also volatilized based on the temperature/moisture and length of time between application and incorporation. It was assumed that manure would be not be incorporated before seven days after application on any land.

PRODUCTION ENTERPRISES

The cropping systems used in this study consist of the major crops grown on East Tennessee dairy farms. The Big Limestone Watershed survey found that most crops were grown continuously. Therefore, corn and alfalfa were not considered in combination in this study. Corn, alfalfa, and hay could be grown to sell or to feed to livestock, or they could be purchased from off the farm, whichever was optimal. Corn silage, rye, and wheat could only be fed to livestock.

Dairy Farms

Production costs, prices, and labor requirements were adapted from the Tennessee Farm Planning Manual. Two herd sizes were considered. Twenty-five percent cull rate was assumed for all farms. A death loss rate of one percent was assumed for cows, and five percent for calves. All bull calves were assumed sold at three days old. Heifer calves could be sold or transferred to the replacement heifer herd. Average milk production was at 16,300 pounds per year. Free stall housing was assumed for both herd sizes, but the 60-cow dairy used a double three herringbone, while the 100-cow herd used a double six herringbone milking parlor.

Confinement Time

The amount of time spent on paved lots directly affects the amount of manure collected. Confinement time on paved lots varies widely. It was assumed for this study that 60 and 100 cow dairies would confine cows twelve hours per day, including milking and feeding time, and replacement heifers for six hours per day.

Enterprise Budgets

Cost and returns were developed for each of the livestock and crop activities. Data for these budgets was obtained from the Tennessee Farm Planning Manual, the Big Limestone Watershed survey, and from personal conversations with extension specialists. All costs and prices were used in developing the budgets were 1990. Inputs and yields for each enterprise were adapted from the survey. Inputs consisted of pesticide, herbicide, fertilizer, and seed levels. Cost and prices were obtained Tennessee Farm Planning Manual and farm supply stores. Prices and yields are listed in Appendix D.

Feed Conversion Coefficients

All livestock feed was converted from bushels and tons to megacalories of energy and kilograms of protein for each unit. This method was utilized by English et al. (1989), and allows the model to meet energy and protein requirements for the dairy cow by shifting between crops purchased and grown on the farm. An example of the feed conversion coefficients are presented in Appendix D.

CHAPTER 4

RESULTS AND CONCLUSIONS

The purpose of this study was to examine farm income effects of requiring a waste management system as a Best Management Practice on a representative East Tennessee dairy farm. Five waste management systems were compared to the base system of daily haul. A waste storage system has been assumed to reduce nitrogen loss and allow for better timing of labor on a dairy. Linear programming was used to evaluate the annual cost of each waste management system in a whole farm setting. Income for each farm was calculated as gross sales minus variable costs and did not include all fixed costs, such as land cost, taxes, and insurance. Total nitrogen loss was also examined for each of the five waste management systems and compared to the base of daily haul. In addition, a marginal cost curve for reducing nitrogen loss was developed for each system.

Two farm sizes were developed from the Big Limestone Watershed survey data, a 100-cow dairy and a 60-cow dairy. Crops on the representative farms were grown to meet nutrient requirements of the dairy herd, and any surplus was sold. The choice of crop enterprises (corn, corn silage, corn silage/wheat, corn silage/rye, pasture, and fescue hay) was held constant for both farm sizes, as was the amount of family labor available. The model was designed to choose between crop enterprises to meet the herd's energy and protein requirements at the least cost.

Changes in farm income and farm organization with each of the five waste management systems will be presented first for the 60-cow and then for the 100-cow farm. The farm income and per cow changes as a result of adding a waste management system are presented in Table 4.1. The addition of a waste management system would have very little effect on farm income especially on a per cow basis. Two factor influence the manure system affect on farm income. The ability of the manure system to save labor and nitrogen fertilizer savings. The two liquid system with irrigation were able to reduce labor required for the daily haul system. This was especially true the 100 cow dairy. The lagoon system were designed to allow the nitrogen in manure to be volatilizated. Thus the lagoon system contributed the least to meeting the crop activities nitrogen needs.

Table 4.1 Change in Farm Income with Waste Management Systems

Item	Daily Haul	Dry Stack	Earthen Pit	Earthen Pit/ Irrigat.	Lagoon Irrigat.	Lagoon/ Irrigat.
60 Cow Herd						
Average Farm Income	68414	64168	66911	69378	66773	68004
Cost:						
Per Farm:	*	-4246	-1503	964	-1641	-410
Per Cow:	*	-70.77	-25.05	16.07	-27.35	-6.83
100 Cow Herd						
Average Farm Income	104654	101193	106562	108421	99749	106173
Cost:						
Per Farm:	*	-3461	1908	3767	-4905	1519
Per Cow:	*	-34.61	19.08	37.67	-49.05	15.19

* Base Farm

The Base 60-Cow Dairy with Daily Haul

The daily haul system was the base used in this study to compare farm level effects of adding a waste management system. Annualized cost of the daily haul system was $2,980, with 350 labor hours required per year. Farm income was $68,414. Optimal crop mix for the 60-cow farm is shown in Table 4.2 The base farm consisted of 36.7 acres of pasture on land type three, 14.5 acres of corn, 60.5 acres of corn silage, 38.3 acres of hay on land type three, and 100 acres of alfalfa grown on land type two. All possible land was rented. The farm used 236.6 hours of hired labor in period one (January/February), 273.6 in period two (March/April), 683 in period three (May/June), 405.3 in period four (July/August), 508.3 in period five (September/October), and 129.4 in period six (November/December). Manure from the waste management system provided 100 percent of the nitrogen requirements for corn, 15 percent for corn silage, and 70 percent.

60-Cow Dairy with Dry Stack

The addition of a dry stack waste management system resulted in farm income of $64,168, $4,246 less than base farm income. The annualized cost of the dry stack was $5,223, with 351 hours of labor required per year. The farm enterprises consisted of 56.5 acres of pasture on land type three, 14.9 acres of corn, 60.1 acres of corn silage, 36.8 acres of hay on land type two, 18.5 acres of hay on land type three, and 63.2 acres of alfalfa on land type two. In period one, 256.6 hours of hired labor were used, 215.6 hours in period two, 519.6 hours in period three, 312.6 in period four, 480.7 hours in period five, and 71.4 hours in period six. Manure from the waste system provided seven percent of nitrogen requirements for corn silage, and 100 percent for corn, hay, and pasture.

Table 4.2 Crops Enterprises from Linear Programming Model - 60 Cow Dairy

Crop	Daily Haul	Dry Stack	Earthen Pit	Earthen Pit/ Irrigation	Lagoon	Lagoon/ Irrigation
			acres			
Pasture1						
Pasture2						
Pasture3	36.7	56.5				
Corn	14.5	14.9	13.9	13.9	13.9	13.9
Corn Silage/Rye						
Corn silage/Wheat						
Corn Silage	60.5	60.1	61.1	61.1	61	61
Hay1						
Hay2		36.8				
Hay3	38.3	18.5	75	75	75	75
Alfalfa1						
Alfalfa2	100	63.2	100	100	100	100
Rented Land 1	62	62	62	62	62	62
Rented Land 2	82	82	82	82	82	82
Labor Requirements						
Time Period						
Period 1	238.6	256.6	180.6	180.6	180.6	180.6
Period 2	273.6	215.6	351.6	274.6	369.6	284.6
Period 3	683	519.6	592	592	592	592
Period 4	405.3	312.6	413	413	413	413
Period 5	508.3	480.7	693.5	616.5	711.5	626.5
Period 6	129.4	71.4	71.4	71.4	71.4	71.4

60-Cow Dairy with Earthen Pit

The 60 cow farm with the earthen pit had farm income of $66,911, $1,503 less than the base farm. Annualized cost of the earthen pit was $5,480, with 437 hours of labor required per year. This farm consisted of 13.9 acres of corn, 61.1 acres of corn silage, 75 acres of hay on land type three, and 100 acres of alfalfa on land type two. In period one, 180.6 hours of hired labor were required, 351.6 in period two, 592 in period three, 413 in period four, 694 in period five, and 71.4 hours in period six. The earthen pit system met 100 percent of the nitrogen requirements for corn, 96 percent for hay, and 43 percent for corn silage.

60-Cow Dairy with Earthen Pit\Irrigation

Farm income for the 60-cow farm with the earthen pit with irrigation system was $69,378, a $964 increase over the base farm. Annualized cost of the earthen pit with irrigation was $5,419, with 284 hours of labor required for each period. The farm consisted of 13.9 acres of corn, 61.1 acres of corn silage, 75 acres of hay on land type three, and 100 acres of alfalfa on land type two. The farm required 180.6 hours of hired labor in period one, 274.6 in period two, 592 in period three, 413 in period four, 616.5 in period five, and 71.4 in period six. The earthen pit/irrigation system met 100 percent of the nitrogen requirements for corn, 27 percent for corn silage, and 100 percent for hay.

60-Cow Dairy with Lagoon

The addition of a lagoon waste management system resulted in a farm income of $66,773, $1,641 more than the daily haul system. Annualized cost of the system was $7,219, with 472 hours of labor required per year. The 60-cow dairy with lagoon was composed of 13.9 acres of corn, 61 acres of corn silage, 75 acres of hay on land type three, and 100 acres of alfalfa on land type two. The farm purchased 180.6 hours of hired labor in period one, 369.6 in period two, 592 in period three, 413 in period four, 711.5 in period five, and 71.4 hours in period six. The system provided 58 percent of the nitrogen requirements for corn, 0 for corn silage, and 100 percent for hay.

60-Cow Dairy with Lagoon/Irrigation

Addition of a lagoon/irrigation system resulted in farm income of $68,004, $410 less than the daily haul system. Annualized cost of the lagoon/irrigation system was $6,887, with 302 hours of annual labor. The farm consisted of 13.9 acres of corn, 61 acres of silage, 75 acres of hay on land type three, and 100 acres of alfalfa on land type two. In period one, 180.6 hours of hired labor were purchased, 284.6 hours in period two, 592 hours in period three, 413 hours in period four, 626.5 hours in period five, and 71.4 hours in period six. The system provided 46 percent of nitrogen requirements for corn, 0 for corn silage and 100 percent for hay.

Selection of Waste Management System for 60-Cow Dairy

The effect on income of adding each waste management system to the 60-cow dairy are presented in Figure 4. The earthen pit/irrigation system increased income by $946, largely because of the nitrogen savings and lower labor requirements. This system allowed more nitrogen to be applied during period two (March/April), when crops could best utilize nitrogen, thus reducing fertilizer purchased. The earthen pit with irrigation had the third lowest annual cost of operation and was the only system to increase farm income over the daily haul base 60-cow farm income.

The lagoon/irrigation system had the lowest negative impact on farm income, with only $410 lost in annual income. The next two most costly systems were the earthen pit and lagoon systems. The earthen pit reduced farm income by $1,503, and the lagoon reduced income by $1,641, because of the high volume of liquid to be handled.

Dry stack had the largest negative impact on income, reducing it by $4,246 as compared to the base farm. The cost of purchased fertilizer accounted for part of this loss in income. Thirty-six acres of pasture were grown on the farm with dry stack.

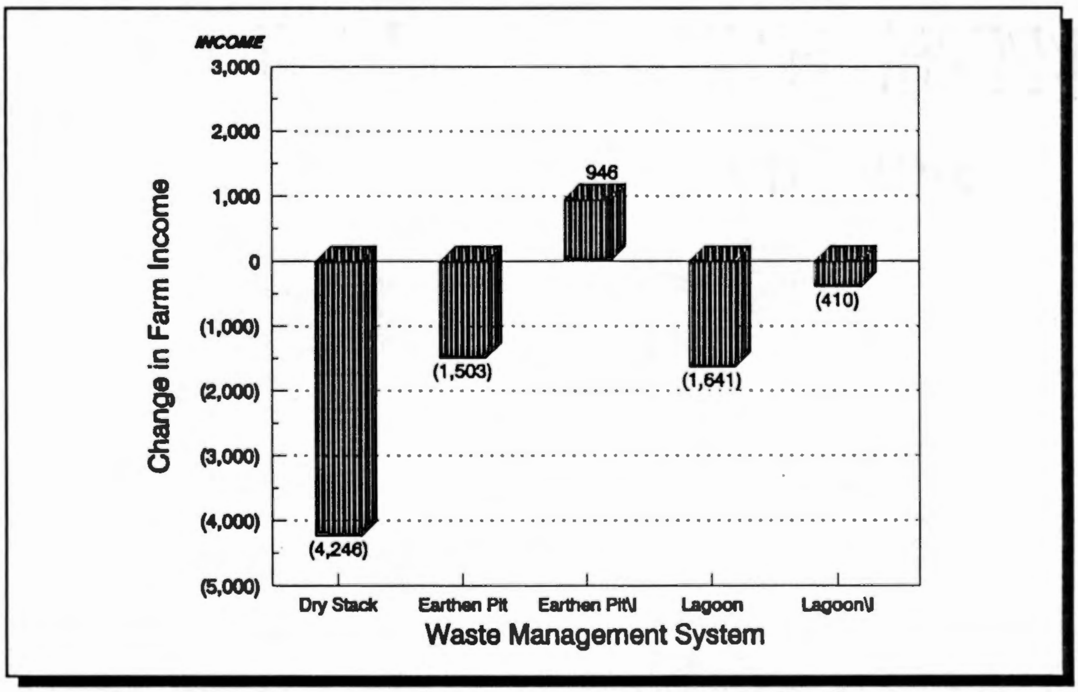

Figure 4. Farm Income Changes for 60 Cow Dairy with Waste Management Systems

Sensitivity Analysis for 60-Cow Dairy

The waste management systems on the 60-cow dairy farm were evaluated for sensitivity to herd size by reducing the herd 50 percent. Original resources of land, labor, and prices remained the same. Only the variables associated with number of cows were reduced, including amount of bedding and manure. The earthen pit/irrigation system produced the highest income with a reduced herd size, although farm income fell $1,545. (Figure 5). Income on the earthen pit farm rose $621 making it the system least sensitive to herd size. The lagoon/irrigation system farm income decreased $1,883, making it most sensitive to herd size. Income on the dry stack farm rose $1,908. The lagoon system without irrigation fell $900, making it the lowest farm income with the reduction in herd size.

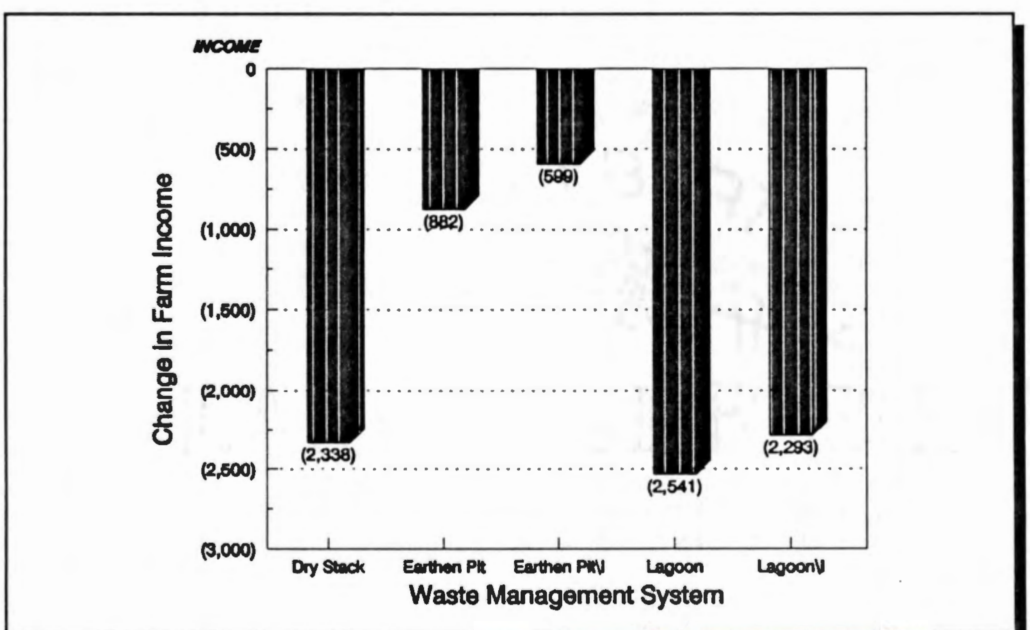

Figure 5. Farm Changes for 60 Cow Dairy with Waste Management Systems, Sensitivity Analysis

60-Cow Dairy with Nitrogen Loss Constraint

Each system was evaluated for net returns effects of reducing allowable nitrogen loss. The amount of allowable nitrogen loss was reduced by increments of 10 percent to the point at which nitrogen loss reduction became infeasible. The lagoon/irrigation was best to meet the nitrogen loss reductions without effecting net returns (Figure 6). The marginal cost of these incremental nitrogen loss reductions reveals the extent to which nitrogen loss could be reduced without affecting net return. Reduction of allowable nitrogen loss had very little effect upon the farm income of the lagoon/irrigation system until 80 percent reduction was reached. Net returns for the earthen pit\irrigation and lagoon were not affected by the nitrogen loss reduction until 70 percent reduction was reached. The earthen pit/irrigation system had a slight advantage in that the marginal cost curve was flatter as compared to the lagoon system. Net return for the daily haul system was not affected by the nitrogen loss restriction until 70 percent reduction was reached. Net returns of dry stack and earthen pit were affected at lower levels of nitrogen loss reductions. The marginal cost of lagoon, earthen pit with irrigation, and lagoon with irrigation alternatives to daily haul were generally less as nitrogen was reduced. Earthen pit and dry stack had greater marginal cost as compared to daily haul (Figure 7).

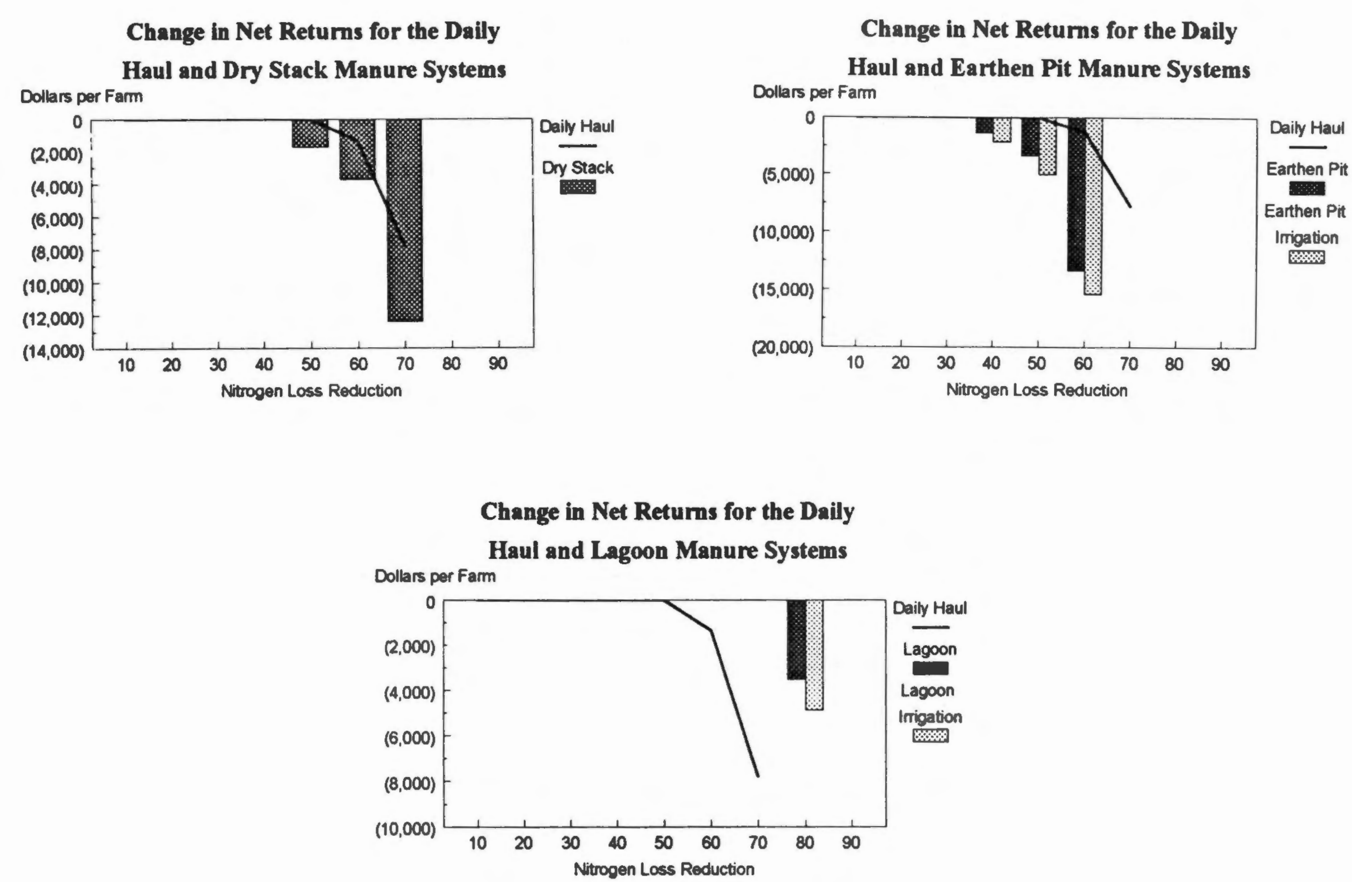

Figure 6. Effects of Nitrogen Loss Reduction on Net Returns - 60 Cow Dairy

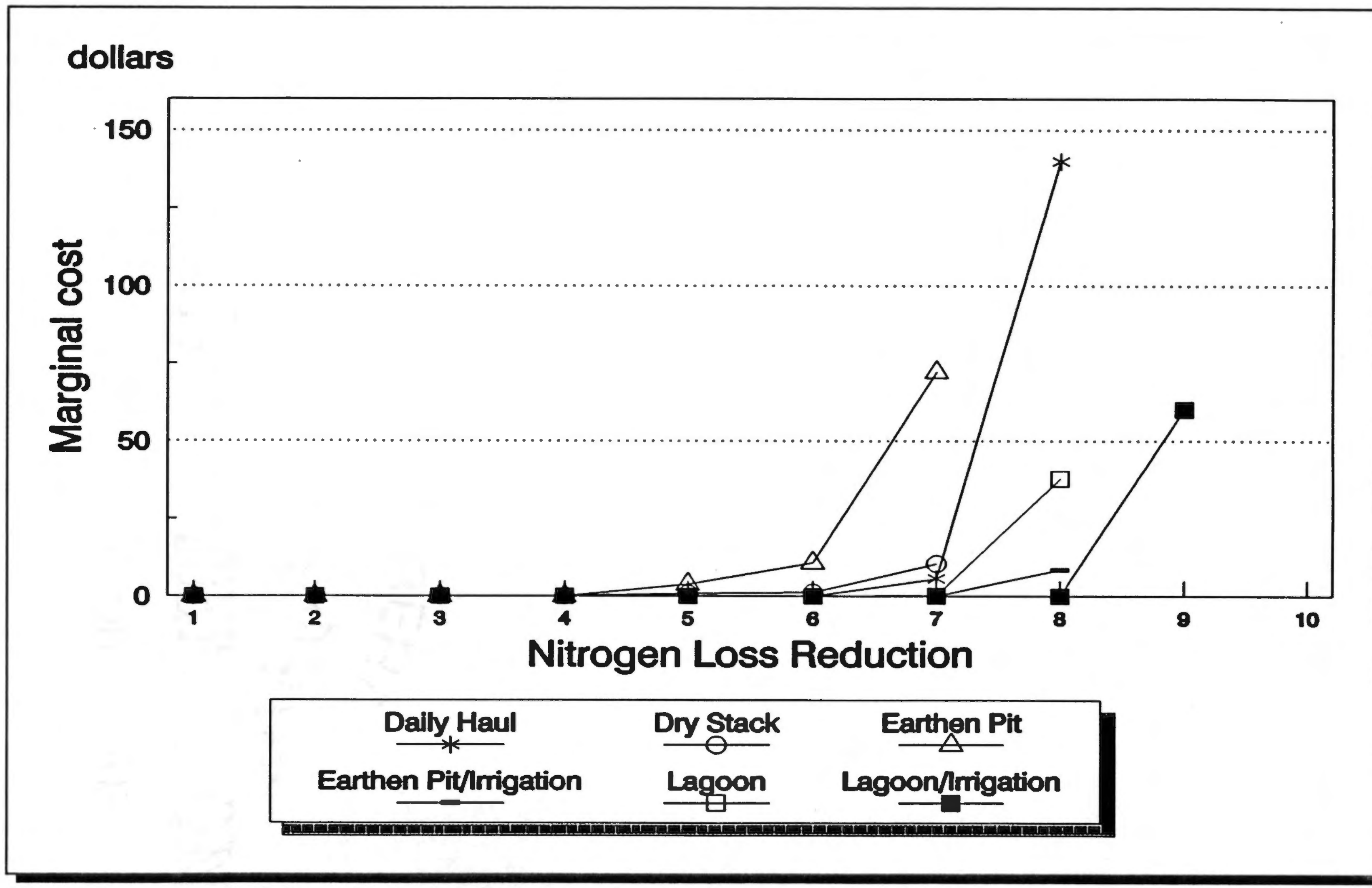

Figure 7. Marginal Cost of Nitrogen Loss Reduction for 60 Cow Dairy with Waste Management Systems

The Base 100-Cow Dairy with Daily Haul

The 100-cow farm using the daily haul waste management system had farm income of $104,654. The annualized cost of the daily haul system was $4,236, with 565 annual hours of labor required. The farm consisted of 61.2 acres of pasture on land type three, 3.2 acres of corn, 100.8 acres of corn silage, 42.8 acres of hay on land type three, and 138 acres of alfalfa on land type two (Table 4.3). The farm required 566 hours of hired labor in period one, 610.1 hours in period two, 1,239.4 hours in period three, 835.4 hours in period four, 918.7 in period five, and 426.8 hours in period six. The daily haul system provided 39 percent of the nitrogen requirements for corn silage, 0 for corn, and 70 percent for hay.

100-Cow Dairy with Dry Stack

Farm income for the 100-cow dry stack farm was $101,193, $3,461 less than base farm income. Annualized cost of the dry stack system was $6,313, with 510 annual hours of labor required. The farm consisted of 73 acres of pasture on land type three, 3.4 acres of corn, and 100.6 acres of corn silage. The farm required 584 hours of hired labor in period one, 516.1 hours in period two, 1,049.2 hours in period three, 721.1 hours in period four, 915.7 hours in period five, and 332.8 hours in period six. The dry stack system provided 100 percent of the nitrogen requirements for corn, 27 percent for corn silage, and 100 percent for hay.

Table 4.3 Crops Enterprises for 100-Cow Dairy

Crop	Daily Haul	Dry Stack	Earthen Pit	Earthen Pit/ Irrigation	Lagoon	Lagoon/ Irrigation
	....			acres	....	
Pasture1						
Pasture2						
Pasture3	61.2	73				
Corn	3.2	3.4	2.2	2.2	2.2	2.2
Corn Silage/Rye						
Corn silage/Wheat						
Corn Silage	100.8	100.6	101.8	101.8	101.8	101.8
Hay1						
Hay2			15.8	20.9		
Hay3	42.8		104	104	104	104
Alfalfa1						
Alfalfa2	138		122.2	117	138	138
Rented Land 1	78	78	78	78	78	78
Rented Land 2	103	103	103	103	103	103
Labor Hours						
Time Period						
Period 1	566	584	472	472	472	472
Period 2	610.1	516.1	724.1	596.1	817.1	603.1
Period 3	1239.4	1049.2	1005.1	977.3	1090.3	1090.3
Period 4	835.4	721.1	851.2	851.3	850.9	850.9
Period 5	918.7	915.7	1216.6	1090.3	1304.4	1090.4
Period 6	426.8	332.8	332.8	332.8	332.8	332.8

100-Cow Dairy with Earthen Pit

The addition of an earthen pit for the 100 cow herd resulted in farm income of $108,421, a $3,767 increase in revenues over the base farm. Annualized cost of the earthen pit was $7,381, with 650 annual hours of labor required. The farm had 2.2 acres of corn, 101.8 acres of corn silage, 15.8 acres of hay on land type two, 104 acres of hay on land type three, and 122.2 acres of alfalfa. Hay was grown instead of utilizing pasture land on this farm. The farm required 472 hours of hired labor in period 1,596.1 hours in period two, 977.3 hours in period three, 851.3 hours in period four, 1,090.3 hours in period five, and 332.8 hours in period six. The earthen pit provided 100 percent of the nitrogen requirements for corn, 51 percent for corn silage, and 100 percent for hay.

100-Cow Dairy with Earthen Pit\Irrigation

Farm income for the 100 cow farm with an earthen pit/irrigation system was $108,421, $3,767 higher than base farm income. The farm had 2.2 acres of corn, 101.8 acres of corn silage, 20.9 acres of hay on land type two, 104 acres of hay on land type three, and 117 acres of alfalfa on land type two. The farm required 472 hours of hired labor in period one, 596.1 hours in period two, 977.3 hours in period three, 836 hours in period four, 1,090.3 hours in period five and 332.8 hours in period six. The earthen pit\irrigation provided 100 percent of the nitrogen requirements for corn, 49 percent for corn silage, and 100 percent for hay.

100-Cow Dairy with Lagoon

Net revenues for the 100 cow farm with a lagoon waste management system was $99,249, a decrease of $4,905 from the base farm with daily haul. The annualized cost of the lagoon was $12,947 with $836 hours of annual labor required. The farm consisted of 13.9 acres of corn, 61 acres of corn silage, 75 acres of hay, and 100 acres of alfalfa grown on land type two. The farm required 180.6 hours of hired labor in period one, 369.6 hours in period two, 592 hours in period three, 413 hours in period four, 711.5 hours in period five, and 71.4 hours in period six. The lagoon system provided 20 percent of the nitrogen required for the corn silage, 100 for corn, and 100 percent for hay.

100-Cow Dairy with Lagoon/Irrigation

Farm income for the 100-cow farm with a lagoon/irrigation waste management system was $106,173, a $1,519 increase over the daily haul system. The annualized cost of the lagoon/irrigation system was $8,745, with 408 annual hours of labor required. The farm consisted of 2.2 acres of corn, 101.8 acres of corn silage, 104 acres of hay on land type three, and 138 acres of alfalfa. The farm required 472 hours of hired labor in period one, 603.1 hours in period two, 1,090.3 hours in period three, 850.9 hours in period four, 1,090.4 hours in period five, and 332.8 hours in period six. The system provided 19 percent of the nitrogen requirements for corn silage, 0 percent for corn, and 100 percent for hay.

Selection of Waste Management System for the 100-Cow Dairy

Adding either an earthen pit, earthen pit/irrigation, or a lagoon/irrigation systems increased farm income over the base farm income (Figure 8). Part of this increase was because of changing crop enterprises and fertilizer savings. For each of the liquid systems, hay acreage was substituted for pasture. Earthen pit/irrigation increased farm income by $3,767, higher than any other system. This increase is due in part to the lower number of annual labor hours required by earthen pit/irrigation as compared to daily haul. Earthen pit/irrigation also allows for better timing of manure disposal, resulting in savings in fertilizer purchased. Earthen Pit\irrigation was followed by earthen pit, which increased farm income $1,908 as compared to daily haul. Lagoon\irrigation also increased farm income by $1,519 over daily haul. Dry stack and lagoon decreased farm income by $3,461 and $4,905 respectively.

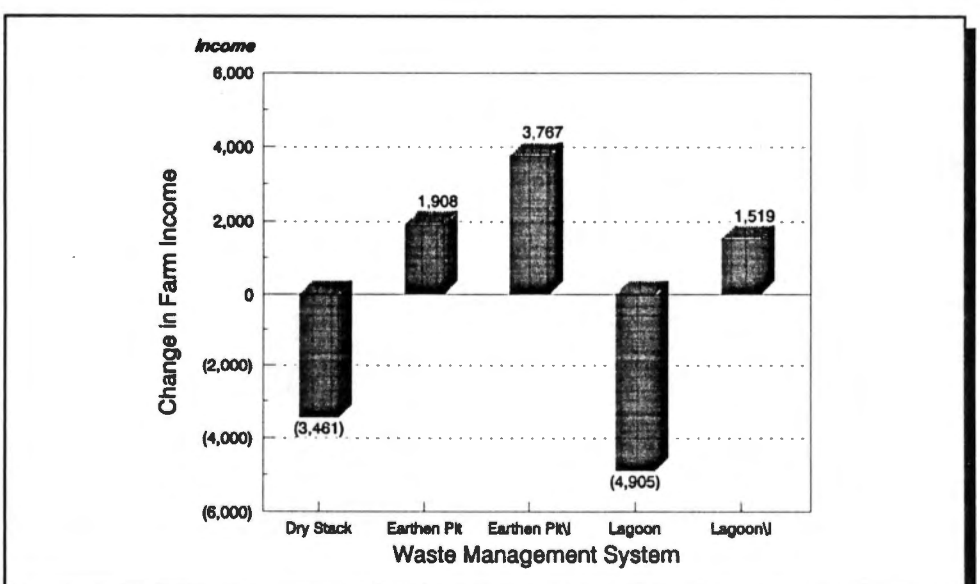

Figure 8. Farm Income Changes for 100 Cow Dairy with Waste Management System

Sensitivity Analysis for the 100-Cow Dairy

The sensitivity of each manure system to herd size was evaluated by reducing the 100-cow herd to 50 cows. After reducing herd size 50 percent, earthen pit/irrigation system provided the highest farm income, at $476 above the base farm income, although actual income fell $3,291 (Figure 9). The earthen pit farm income fell $2,736. The lagoon/irrigation system fell to $3,397, making it the most sensitive to changes in herd size. Although the earthen pit and lagoon/irrigation systems compared favorably to the daily haul system with 100 cows, a reduction in herd size caused both to drop below base farm income levels. The lagoon farm income rose to $2,583. The dry stack farm income rose to $1,101 below base farm income, making it the least sensitive to changes in herd size.

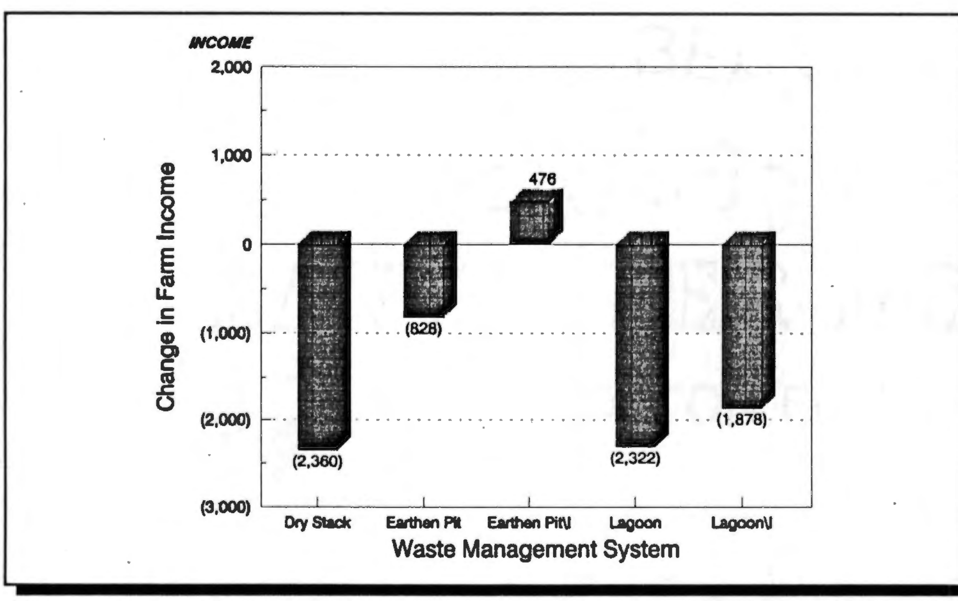

Figure 9. Farm Income Changes for 100 Cow Dairy with Waste Management Systems, Sensitivity Analysis

100-Cow Dairy with Nitrogen Loss Constraint

Each waste management system was evaluated for the marginal cost of reducing the nitrogen loss allowable. The nitrogen loss constraint was reduced in increments of ten percent until it became infeasible to meet the constraint.

The same method of developing the nitrogen loss constraint was used for the 60 cow dairy was also used for the 100 cow dairy. The nitrogen loss constraint the maximum amount of nitrogen for a given farm. Caution should be used in interpreting the nitrogen loss affect on net return. The nitrogen loss does show among the different system how each system is able to meet the nitrogen loss reduction.

The daily haul system for the 100-cow dairy was best able to meet the nitrogen loss reduction without affecting net returns (Figure 10). The reduction of nitrogen loss had very little effect on the daily haul and lagoon/irrigation systems until 60 percent reduction was reached. Daily haul did have a flatter curve than the lagoon/irrigation system. Dry stack system was not affected until 40 percent reduction was reached. The dry stack was followed by the earthen pit/irrigation and earthen pit. Again, the systems were able to meet the nitrogen loss reduction by spreading less manure on more ground. More manure was disposed of on pasture and hay ground and less on corn and corn silage. The marginal cost of alternatives to daily haul were generally greater as nitrogen was reduced (Figure 11).

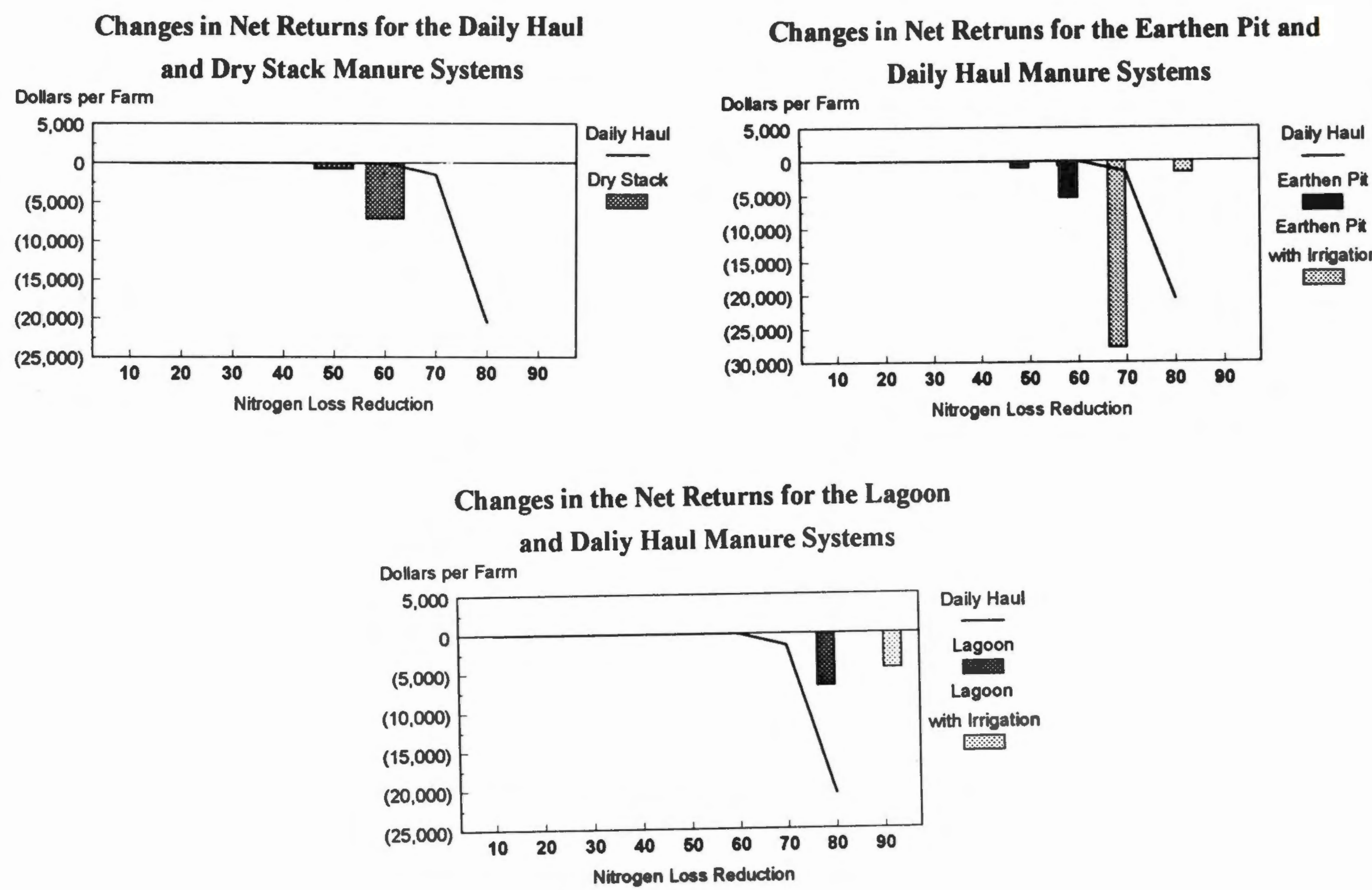

Figure 10. Effects of Nitrogen Loss Reduction on Net Returns - 100 Cow Dairy

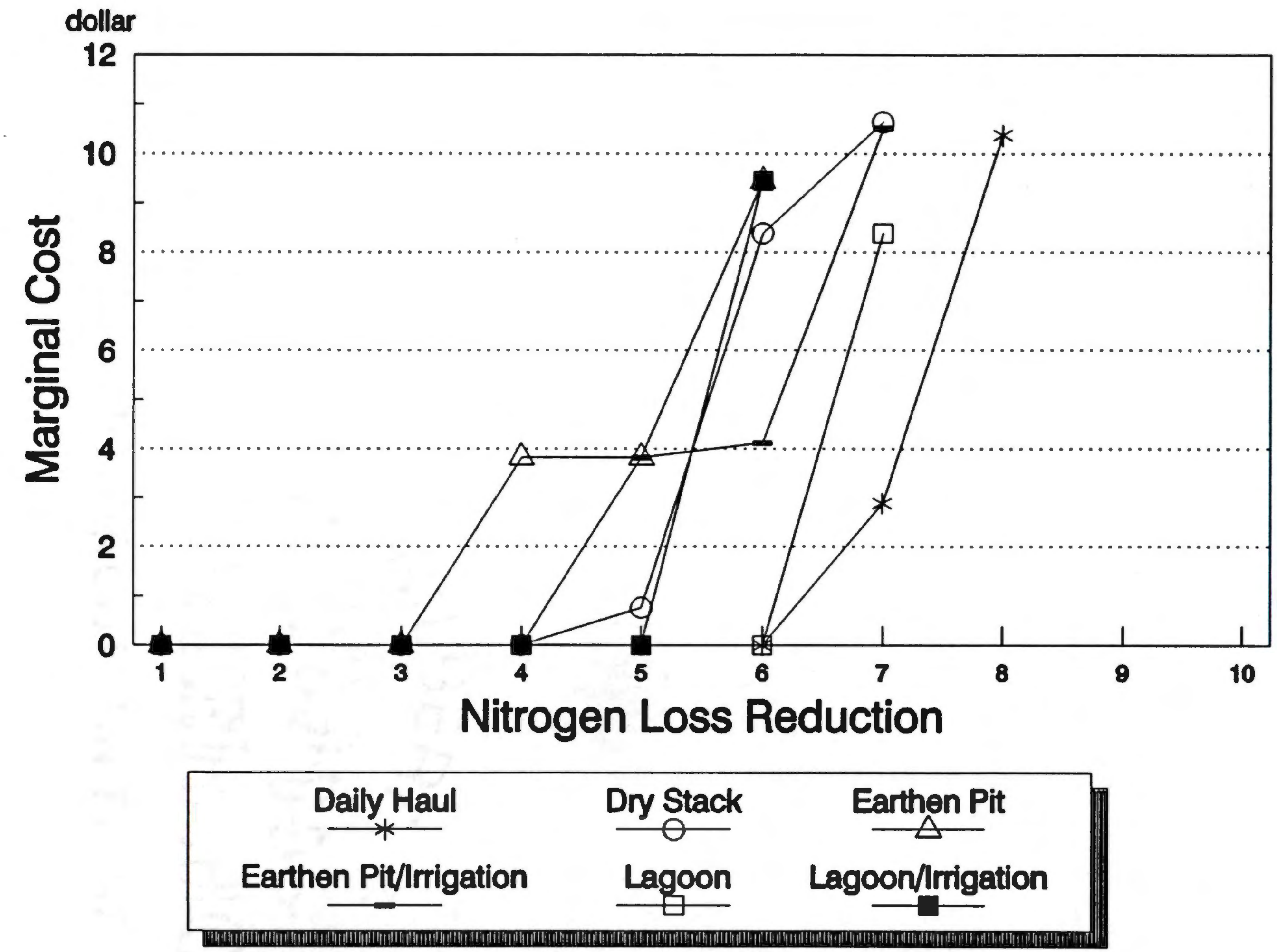

Figure 11. Marginal Cost of Nitrogen Reduction for 100 Cow Dairy

Comparison of the 60- and 100-Cow Dairies

The objective of maintaining farm income and reducing nitrogen loss were met in different ways on the two farm sizes. The 100-cow dairy could actually increase farm income by adding a waste storage system. Three waste management system earthen pit earthen pit/irrigation, lagoon/irrigation increased farm income. However, the daily haul system could accommodate the greatest restriction on nitrogen loss without affecting farm income. The earthen pit was least able to meet the nitrogen loss constraint without adversely affecting farm income.

Addition of a waste storage system to the 60-cow dairy reduced farm income except the earthen pit/irrigation system. Lagoon/irrigation, followed by earthen pit/irrigation, was best able to meet the nitrogen loss reduction. The 60-cow dairy utilizing the earthen pit/irrigation system was able to meet the objective of maintaining farm income and reducing nitrogen loss.

Part of the difference between the marginal cost of reducing nitrogen loss on the 60- and 100-cow dairies may be attributed to the land to cow ratio. This was discussed in the study by Ashraf and Christensen (1975). A larger dairy herd with a small land-to-cow ratio would mean more manure being spread on less land. They found that farms having a land-to-cow ratio of 1.21 had 33 percent less income per cow as compared to farms with a 3.14 land-to-cow ratio. In this study the 60-cow dairy had a land-to-cow ratio of 4.15 compared to a 3.46 land to cow ratio for the 100-cow dairy.

The nitrogen loss constraint was developed by assuming all the nitrogen would be applied in each of the six time periods. A ratio was developed from the amount of nitrogen applied and the amount loss for each time period. The total amount of nitrogen applied in each time period taken from the GAMS model was then multiplied with each of the nitrogen loss ratio numbers developed from EPIC. This method of developing a nitrogen loss constraint assumed the maximum amount of nitrogen loss for a given farm and waste management system. The method of developing the nitrogen loss constraint can be attributed to the large reduction of nitrogen loss before affecting farm income.

The nitrogen loss restrictions were met by applying less manure to more land and by shifting manure disposal from the higher nitrogen loss crops such as corn and corn silage to pasture and hay. As the nitrogen loss restriction was increased, more of the nitrogen requirements for corn and corn silage were met by purchased fertilizer. When the model could not dispose of the manure on pasture or hay, the solution became infeasible. The model required the nitrogen from the manure system to be applied to crops activities. All crops could not have manure spread in all time periods, except for pasture. The lagoon/irrigation system was better able to meet the nitrogen loss restrictions, followed by earthen pit/irrigation, lagoon, daily haul, dry stack and then earthen pit. The marginal cost curve shows that dairy farms could met environmental requirements by better management of nitrogen fertilizer. The nitrogen loss reduction had very little effect on farm income until nitrogen loss was reduced to 60 percent. Better management of fertilizer and manure could actually increase farm income. It should be note the nitrogen loss constraint was developed as a worst case. The interpretation of the nitrogen loss percent affect on farm income should be viewed with caution.

CHAPTER 5

SUMMARY AND LIMITATIONS

The objective of this study was to develop a linear programming model of two farm sizes to select the best waste management system based on farm income and environmental constraints on nitrogen losses. Many earlier studies had used a partial budgeting approach which could not account for competition for resources.

Six waste management systems were evaluated for their impact on farm income. Presently, most dairy farms in the Big Limestone Watershed have a daily haul system without a storage structure. This study assumed that external forces could require dairy farms to include a storage system. The farm income impacts of five storage systems were compared to a base farm using daily haul. Under the assumptions of this study, the earthen pit with irrigation was selected as the best waste management system for both the 60-cow farm and the 100-cow farm, when compared on the basis of farm income. On the 60-cow farm, all other systems had a negative impact on farm income, with dry stack having the lowest income.

The 100-cow dairy had three waste management systems which increased farm income as compared to the daily haul system. Earthen pit with irrigation and lagoon/irrigation had positive impact on farm income. Only the dry stack and lagoon systems had a negative impact. However, daily haul was the system with the lowest marginal cost of reducing nitrogen loss.

Schaffer and Jacobs also found that as nitrogen losses were reduced, farm income went down accordingly, except for the daily haul system. Young et al. (1985) found that storage of manure actually increased the amount of nitrogen loss for a given farm. These earlier findings are reinforced by the results of this study. Reducing nitrogen loss for the 100-cow dairy had the least effect on farm income without a manure storage system. Earthen pit/irrigation had the largest positive impact on farm income but was most costly in reducing nitrogen loss.
Addition of a waste management system was expected to produce changes in crop mix, but few changes occurred. Most of the differences in crop mix were between liquid and solid manure handling systems.

When comparing the ability of the waste management systems to reduce nitrogen losses, daily haul was better able to meet the nitrogen restriction for the 100-cow dairy. The earthen pit waste system was least able to accommodate nitrogen loss reductions.

Limitations

The two representative farms in this study were developed from survey data, personal conversations with Agricultural Extension Service specialists, and the Guide to Farm Planning. Extensive care was taken to describe a typical dairy farm on the Big Limestone Watershed. Many differences exist between farms. Any changes in land available, prices, or yields per acre could alter the results of this study.

Several Agricultural Extension Service and Soil Conservation Service personnel were consulted in developing the six typical waste management systems for this study. However, numerous variations could be considered, and any changes in system components or equipment size could alter results. The study assumed that waste management systems could be added to any farm. However, in some locations, underlying rock formations would preclude the use of lagoons or earthen pits.

Other studies have found that the time before manure incorporation is related to nitrogen availability. Early incorporation has been found to significantly increase its nitrogen value. In this study, it was assumed that manure could not be incorporated in less than 7 days, due to the volume of liquid to be spread.

In this study, nitrogen loss was not captured from the barnlot. EPIC is a field level model. Measuring the nitrogen loss from the barnlot could alter the results, changing the marginal cost curves of each of the waste management system.

Finally, this study only analyzed farm level effects of waste management systems, including annual operating costs. Farmers might also be concerned with the initial cost of adding a waste management system.

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APPENDICES

APPENDIX A

Date______________________

Interviewer_________________________

Name______________________ Time of Interview____________________

Address ____

____

Telephone ____________________

This survey is being conducted by the University of Tennessee and the Soil Conservation Service (SCS) in order to gather information from farmers like you, to assess the economic and environmental impacts of current tillage and recommended conservation systems. Secondly, the SCS and the University of Tennessee will use the information to evaluate different means of providing assistance to you.

Although participation in this survey is voluntary, your cooperation will assure that farmers are better served by government agencies. All information gathered will be kept confidential. The information from your responses will be combined with information obtained from other farmers and only the group results will be reported.

The following questions are intended to provide an overall view of your farming operation. Questions later in the survey pertain to conservation practices and your involvement in government programs. Again, <u>all information in this survey will be kept confidential.</u>

Note to interviewer: You should ask the screening questions before proceeding with the interview.

Did you earn at least $1,000 in gross sales last year on your operation?

Are you the principle decision maker for this operation?

*****If No to either of these questions stop the interview.*****

Do you feel small-scale farmers are having a harder time financially now than 5 years ago? (record answer here)

____

____

____

____

Do you feel conserving the soil is an important issue for farmers today?

____

____

____

Farm Buildings and Equipment

I would like to ask you some questions concerning buildings and equipment. What buildings do you have on this operation and what is the size (in square feet), age, and condition of each building?

Kind	Size (Dimensions)	Approximate Age	Condition (E,G, F, P)**
Main Barn & other barns			
Granary			
Silo (type)			
Machinery Shed			
Milk storage(other)			
Bulk tank			
Pipeline Milker			
Milking Parlor			
Tenant House			
Tenant House			
Operator's Dwelling			
Other			

If you have a milking parlor, what is the type?______________________________.
Example (double herringbone)

**E, G, F, & P, stand for Excellent, Good, Fair, and Poor.

Farm Buildings and Equipment

Additional space if needed for buildings and equipment

Kind	Size (Dimensions)	Approximate Age	Condition (E,G,F,P)**

**E, G, F, & P, stand for Excellent, Good, Fair, and Poor.

Crops

I would like to ask you some questions concerning crops grown on your operation last year. What crops did you grow on this operation? How many acres of each crop? (exact number) What was your yield per acre last year? What was the selling price per unit? (e.g. dollars/bushel) How much of the crop did you use in this operation (in percent)? Dollars should be in gross sales.

	Crop	Acres Harvested	Yield/Acre	Sale Price/unit	Percent fed to Livestock
1	Corn grain				
2	Soybeans				
3	Oats				
4	Wheat				
5	Corn Silage				
6	Tobacco				
7	Fescue Hay				
8	Alfalfa				
9	Other Hay				
10	Grain Hay				
11	Vegetables 1.				
11	2.				
11	3.				
12	Grain Sorghum				
13	Green Chop				
14	Conservation Reserve				
15	Pasture				
16	Idle Land				
17	Other Land				
18	Cotton				

Circle any acres doubled cropped.

Crops

Additional space if needed for crops

	Crop	Acres Harvested	Yield/Acre	Sale Price/unit	Percent fed to Livestock
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					

Please add acreage of each crop and check with total acreage given before going to the next section.

Circle any acres doubled cropped.

Was any pasture acreage also used for hay? acres________.

How many acres do you farm? _______, acres owned_______, acres rented______.

Tillage and Planting Practices

This section should include all crops grown on the farm last year. **You should use the number of the crop on the previous table.** Use the **numerical code** for the tillage practices that are given below. For each crop record the different tillage practices and crop rotation. Example: Corn grown continuously and in rotation with alfalfa would be recorded as **separate crops.** The same would be true for no-till and moldboard plow for each crop. **You should use the crop numbers from page 5 or 6.**

Crop	Acres	Previous Crop				Tillage & Planting Practice *
		90	89	88	87	

Use the numbers that correspond to tillage practice & planting practice used on this crop.
If the tillage practice was a custom operation, enter with c in parentheses.
Example: (c,1)

* Tillage Practices

1. Moldboard Plow
2. Chisel Plow
3. Subsoiler
4. Disk
5. Cultipacker
6. Grain Drill
7. Transplanter
8. Apply Fertilizer
9. Apply Herbicide
10. Harrow
11. Cultivator
12. No-till

Tillage and Planting Practices

Additional space for tillage practices

Crop	Acres	Previous Crop				Tillage & Planting Practice *
		90	89	88	87	

Use the numbers that correspond to tillage practice & planting practice used on this crop.
If the tillage practice was a custom operation enter with c in parentheses. Example: (c,1)

* Tillage Practices

1. Moldboard Plow
2. Chisel Plow
3. Subsoiler
4. Disk
5. Cultipacker
6. Grain Drill
7. Transplanter
8. Apply Fertilizer
9. Apply Herbicide
10. Harrow
11. Cultivator
12. No-till

Conservation Practices

Did you use any of the following conservation practices in 1991? These practices will be by crop. **Acres used for each crop. You should use the crop numbers from page 5 or 6.**

	Yes	No	Crop	Acres Used	Crop	Acres Used	Crop	Acres Used
Strip cropping								
Contours								
Terraces								
Conservation tillage								
Crop residues left on Surface								
Diversion ditches								
Winter cover crop								
Spring vs Fall plowing								
No-till								
Grass waterways								
Other								

Do you own any no-till equipment?___Yes ___No If yes, what type of equipment?

____

____

____

Machinery

In this section we need to know what machinery you own on this operation. What is the size (width, horse power), model year, year machinery was purchased, and the approximate value of the machinery for each.

Kind	Size	Model year	Year Purchased	Approximate Value
Tractor				
Tractor				
Tractor				
Truck				
Truck				
Disk Harrow				
Disk				
Plow				
Plow				
Cultimulcher				
Cultivator				
Fertilizer Distributor				
Transplanter				
Grain Drill				
Combine				
Wagon				
Wagon				
Trailers				
Hay Elevator				
Hay Baler (round)				
Hay Baler (square)				
Hay Tether				
Hay Rake				
Cotton Picker				

Machinery

Additional space for machinery

Kind	Size	Model year	Year Purchased	Approximate Value
Manure Loader				
Bush Hog				
Planter				
Sprayer				
No-Till Drill				
No-Till Planter				
Other				
Other				
Other				

Fertilizer

Was any fertilizer applied on any crops last year? If so, continue. **Record each different application procedure of fertilizer and lime for each crop in pounds per acre.** Type of fert. would be bag, bulk, anhydrous ammonia. What is the analysis? Ex.(10-10-10) How much did you apply to each crop and when did you apply fertilizer? Did you apply any lime? If so, what was the month of application and amount for each crop?

Crop	Type of Fert.	Analysis			Appl. Rate (per acre)	Date of Fert. Appl.	Appl. Rate Lime	Date of Appl. Lime
		N	P_2O_5	K_2O				

b. Do you reduce nitrogen application for crops following a legume?

YES______ NO______

c. If yes, what percent do you reduce nitrogen fertilizer with any of these crops in a rotation:

Alfalfa? ______

Soybeans? ______

Other? ______

Pesticides

The following section covers the pesticides you used on your operation last year. **Record each time you used a different pesticide on each crop.** Pesticides include Herbicides, Insecticides, Fungicides. Form will include Granular, Liquid, Powder, and concentration percent. Record the approximate date of pesticide application. (month is sufficient) What was the brand-name, application rate, form, timing of the pesticides applied to each crop? Use the code below to answer how each pesticide container is disposed.

Crop	**Brand Name**	**Form and %**	**Appl. Rate**	**Appl. Meth.**	**Date**	**Dis. Meth**

Disposal method:

1. throw in trash
2. bury on farm
3. burn
4. other

If indicated other, what means is used to dispose of pesticide containers.

A. Are you familiar with current federal and state pesticide laws and regulations?

Yes____ No____

B. Do you have a license for pesticides which require one?

Yes____ No____

C. Do you mix your pesticides in a special area? Yes____ No____
If yes, what area is used and why was this area chosen? (circle as many as apply)

1. Near equipment used to apply pesticide
2. Away from household
3. Away from animals
4. Away from streams or water supply

D. Do you have a specific storage place for excess pesticides?

Yes____ No____

E. How do you deal with pesticide spills?

F. Would you be willing to return empty pesticide containers to the point of purchase, if such a service were available?

Yes____ No____

G. If the answer above is **no**, list a reason why?

____ 1. No safe way to transport opened containers back to store
____ 2. Not necessary
____ 3. Inconvenient
____ 4. Other, please specify________________________________

Pesticides

Additional space for pesticides

Crop	Brand Name	Form and %	Appl. Rate	Appl. Meth	Date	Dis. Meth

Disposal method:

1. throw in trash
2. bury on farm
3. burn
4. other

   If indicated other, what means is used to dispose of pesticide containers.

____

Livestock Number and Production

Do you have any livestock on this operation? If so, what kind do you have? For each kind what is the present number, number you sold last year(1991), and the total dollars for the animals sold?

Kind of Livestock	Present Number	Number Sold 1991	Total Dollars
Milk Cows			
Dairy Heifers (1 year)			
Dairy Calves (under 1 year) bull or heifer			
Beef Cows			
Beef heifers > 500 lbs			
Steers > 500 lbs			
Beef Calves < 500 lbs			
Bulls (serviceable)			
Sows			
Boars			
Hogs, >40 lbs			
Pigs, <40 lbs			
Ewes			
Hens			
Broilers			
Other Livestock			

Do you share ownership in any of the animals mentioned above? __Yes __No
If yes, describe the ownership arrangement.

____

____

Manure Handling

A. Do you have any manure storage facilities? If so, what type do you have?

Type	Capacity
Solid, Bunk	tons
Solid, Ground	tons
Liquid, Pit	gal.
Liquid, Lagoon	gal.
Other	

B. Do you have any manure handling equipment? If so, what type. (Indicate by a ✓ in the appropriate boxes)

Liquid:		Solid:	
Pump		Skid Loader	
Flow		Tractor & Loader	
Other		Mechanical Barn Cleaner	
		Other	

C. What type of manure spreading equipment do you have on this farm? Indicate which type.

	Capacity	Rate
Liquid, above ground	gal.	/acre
Liquid, injection	gal.	/acre
Solid	bu.	/acre
Other		/acre

D. On fields that you applied manure, did you reduce your commercial fertilizer application?

Yes______ No______

E. Has the manure you applied ever been sampled for nutrient content?

Yes_______ No______

F. Do you plan to make any changes in your method of manure handling?

Yes______ No_______

If answered yes, what changes

____

____

____

____

G. What is the distance from your main livestock housing facilities to the nearest stream?

_____ feet

H. What obstacles do you have in making changes in your manure handling system?

___too expensive

___lack of information

___do not feel a need to change the system

___other, please specify_______________________________________

This section will cover livestock management practices. These answers apply to the year 1991.

Questions 1-5 deal with dairy only.

1. If the operation is a dairy farm, how many cows do you normally milk?_______

2. What was the average pounds of milk per cow in 1991? ________

3. Do you have plans to change the number of cows you milk? Yes____ No____
   If yes, what changes do you plan to make?

   ____

   ____

4. Do you sell grade A or manufactured milk? _______________

5. If manufactured, do you have any plans to change to grade A?
   Yes____ No____

All amounts of feed should be per day. Questions for Beef, Dairy, and/or Swine

6. Did you feed silage? Dairy Yes_____ No_____ (If No, go to **question 8**)
   Beef Yes_____ No_____

7. How much per cow? Per Replacement Heifer?
   Dairy per cow_____ per heifer_____
   Beef per cow_____ per heifer_____

8. Did you feed a concentrate? Dairy Yes_____ No_____(If No, go to **question 10**)
   Beef Yes_____ No_____

9. How much per cow? Per Replacement Heifer?
   Dairy per cow______ per heifer______
   Beef per cow ______ per heifer______

10. Did you use artificial breeding? Dairy Yes____ No____(If No, go to **question 12**)
    Beef Yes____ No____

11. If yes, go to **question 10**, what percentage? Dairy ____%
    Beef ____%

12. Did you purchase hay? Yes______ No______ (If No, go to **question 14**)

13. How much? Alfalfa______ Mixed fescue______ Other______

14. What percent of your livestock do you normally cull each year? Dairy ________%
    Beef ________%

I would like to ask you some questions regarding participation in government programs.

1. Have you participated in any programs of the following government agencies in the last 5 years?

Federal Crop Insurance	Yes__	No__
Farmers Home Administration	Yes__	No__
Conservation Reserve Program	Yes__	No__
Farm Credit Service	Yes__	No__
Commodity Programs	Yes__	No__

If answered Yes to commodity programs, which commodities?

____

____

____

2. Have you received any information from the following government agencies in the last two years? Place a check in the appropriate agencies

	SCS	Extension	ASCS
1990	____	____	____
1991	____	____	____

3. How often did you receive information from these government agencies? By which means? Place response under appropriate agencies.

	SCS	Rate	Extension	Rate	ASCS	Rate
Letter	____	____	____	____	____	____
TV	____	____	____	____	____	____
Radio	____	____	____	____	____	____
Newspaper	____	____	____	____	____	____
Personal Contact	____	____	____	____	____	____

Rate
1 Once a month
2 Twice a month
3 More than twice a month
4 None

The following are questions concerning how you receive information.

1. Rank the quality and usefulness of the pesticide use and effectiveness information you have received from the following sources:

(1 is the highest and 10 is the lowest ranking, use N/A for sources not used)

Soil Conservation Service	1	2	3	4	5	6	7	8	9	10	N/A
Extension Service	1	2	3	4	5	6	7	8	9	10	N/A
ASCS	1	2	3	4	5	6	7	8	9	10	N/A
Supply Store Personnel	1	2	3	4	5	6	7	8	9	10	N/A
Company Sales Representatives	1	2	3	4	5	6	7	8	9	10	N/A
Company Product "800" numbers or related hotlines	1	2	3	4	5	6	7	8	9	10	N/A
Farming Magazines	1	2	3	4	5	6	7	8	9	10	N/A
Advertisements	1	2	3	4	5	6	7	8	9	10	N/A
Other Farmers	1	2	3	4	5	6	7	8	9	10	N/A

2. Rank the quality and usefulness of the soil conservation information you have received from the following sources:

(1 is the highest and 10 is the lowest ranking, use N/A for sources not used.)

Soil Conservation Service	1	2	3	4	5	6	7	8	9	10	N/A
Extension Service	1	2	3	4	5	6	7	8	9	10	N/A
ASCS	1	2	3	4	5	6	7	8	9	10	N/A
Supply Store Personnel	1	2	3	4	5	6	7	8	9	10	N/A
Company Sales Representatives	1	2	3	4	5	6	7	8	9	10	N/A
Company Product "800" numbers or related hotlines	1	2	3	4	5	6	7	8	9	10	N/A
Farming Magazines	1	2	3	4	5	6	7	8	9	10	N/A
Advertisements	1	2	3	4	5	6	7	8	9	10	N/A
Other Farmers	1	2	3	4	5	6	7	8	9	10	N/A

3. How often during the year do you receive pesticide use and handling information from the following sources? **(Circle one answer per row)**

Soil Conservation Service	Frequently	Infrequently	Not At All
Extension Service	Frequently	Infrequently	Not At All
ASCS	Frequently	Infrequently	Not At All
Supply Store Personnel	Frequently	Infrequently	Not At All
Company Sales Representatives	Frequently	Infrequently	Not At All
Company Product "800" numbers or related hotlines	Frequently	Infrequently	Not At All
Farming Magazines	Frequently	Infrequently	Not At All
Advertisements	Frequently	Infrequently	Not At All
Other Farmers	Frequently	Infrequently	Not At All

4. Rank the top three methods of how you receive information concerning pesticide use and handling? **(Rank top three 1,2,3)**

___Television ___Field Days

___Farm Visits by Salespersons ___Radio

___Office or Store Visits ___Informal Conversations

___Newspapers ___Direct Mailings

___Magazine ___Container Labels

Personal Information

I would like to ask you some questions about yourself.

1. Age ____

2. Highest level of education ______

3. Do you work off the farm?
   ____Yes
   ____No

4. (If Yes to #3) When do you do most of your farm work?
   ____

5. If you work off-farm, into which of the following ranges does your monthly off-farm income fall?

____ less than $600
____ $600 - $800
____ $900 - $1,000
____ $1,000 - $1,200
____ $1,200 - $1,400
____ $1,400 - $1,600
____ $1,600 - +

6. Does your spouse work off the farm? ____Yes ____No.

   If Yes, which of the following ranges would best describe his/her monthly salary?

____ less than $600
____ $600 - $800
____ $800 - $1,000
____ $1,000 - $1,200
____ $1,200 - $1,400
____ $1,400 - $1,600
____ $1,600 - +

7. If a part time farmer, what percent of your yearly income do you receive from farming?

   _____less than 10%
   _____25%
   _____50%
   _____75%
   _____more than 75%

8. How many years have you been farming? ______

9. In which of the categories would your annual gross sales from all farming operations fall.

____ less than $ 5,000
____ $5,000 - $15,000
____ $15,000 - $30,000
____ $30,000 - $50,000
____ $50,000 - $80,000
____ $80,000 - $120,000
____ $120,000 - $150,000
____ $150,000 - $180,000
____ $180,000 - +

10. What would you estimate the present value of the land and buildings you own to be?

____ under $70,000
____ $70,000 - $110,000
____ $110,000 - $150,000
____ $150,000 - $200,000
____ $200,000 - $300,000
____ $300,000 - $400,000
____ $400,000 - $500,000
____ $500,000 - +

11. Do you have a mortgage on your farm at present? ____Yes ____No

12. What range would best describe the present mortgage on your land and buildings? (This would include home located on farm)

___ less than $20,000
___ $20,000 - $50,000
___ $50,000 - $75,000
___ $75,000 - $125,000
___ $125,000 - $175,000
___ $175,000 - $250,000
___ $250,000 - +

13. Do you have any intermediate term loans (1-5 years)? Yes____ No____

If Yes, what range would the intermediate loans fall?

___ less than $5,000
___ $5,000 - $10,000
___ $10,000 - $20,000
___ $20,000 - $50,000
___ $50,000 - +

14. Do you have any short term loans (under 12 months)? Yes____ No____

If Yes, what range would the short term loans fall?

___ less than $2,000
___ $2,000 - $5,000
___ $5,000 - $10,000
___ $10,000 - $20,000
___ $20,000 - +

Thank you for the time and effort you have taken in answering the survey.

APPENDIX B

[1]Labor hours required (per budget period) were estimated as: (.38 x #days in budget period) + (.0026 x $ft.^3$ lot waste collected) (adapted from Moore, Morgan and Ashraf).

[2]Twenty-five percent of the fixed daily labor requirement (.38 hr.) was subtracted from the labor equation to arrive at tractor/equipment hours required.

[3]AT was calculated as: (gallons of wastes collected/(gpm rating of pump / 60) x 8 (a constant). TT was approximated as: (gallons of wastes collected / gpm rating of pump) /60.

[4]Labor hours for DH systems (all herd sizes) were calculated for each budget period (BP) as: (.25 x 1000 ft^3 of wastes collected) + (.1 x %TOL x #days in the BP). Required tractor/equipment hours for each BP were determined by subracting a "dead time" variable from associated labor hours. Adapted from Moore, Morgan).

[5] Application labor hours were calculated as: 1.5 + (.25 x 1000 ft^3 of wastes stored). Tractor/equipment hours were figured by subtracting a dead time (DT) constant from synthesized labor hours. DT was calculated by the equation: 1.5 x .333 + .5 hours (adapted from More, Morgan)

[6]Labor hours for Earthen Pit systems were approximated by the equation: 1 + (.75X x 1000 ft^3 of stored wastes) + .5 (AP). The agitation coefficient (X) equaled ..2515 .325 for 60 and 100 cow herds respectively. The variable (AP) represented the number of additional agitation points required (>1) due to size of facility.

[7]Tractor/equipment hours for Earthen Pit systems were calculated as: .5 + (X x 1000 ft^3 of stored wastes) + .25(AP). For the lagoon systems the equation used was: .5 + (.8X x 1000 ft^3 of stored wastes). The coefficient (X) retained its value used in the labor calculation.

[8]Labor hours were synthesized according to the derived equation: 2 + (.75X x 1000 ft^3 of stored wastes) + .5(AP). For lagoon systems, (X) equaled .12 for 60, and 100 cow herds.

[9]Tractor/equipment hours were calculated by the equation: 1 + (X x 1000 ft^3 of stored wastes) + .25(AP). The agitation coefficient (X) had the same values as in the labor equation.

[10]Labor hours were clculated as: ((.31 x %TOL) + [(X) x 1000 ft^3 of stored wastes]. In this instance, (X) equaled 1.76 for both herds.

[11]Labor hours were calculated as: 5 + [(X) x 1000 ft^3 of stored wastes]. Here (X) has the same values as defined for Daily Haul.

[12]Labor hours required during each "hauling period" was estimated as: 2 + [(X) x1000 ft^3 of wastes stored] where (X) equals 1.2 for both herds.

[13]Tractor/equipment hours required for the hauling process were estimated by the equation: .5 + [(X) x 1000 ft^3 of wastes stored] where (X) retained the same values as in the labor calculation.

[15]One "set" was assumed to allow coverage of 10 acres; an average one hour of labor was required per set. Total hours of labor for each irrigation task were calculated as: (total acres covered / 10 x 1.0) + 2. It was assumed that one-half acre inches (13,577 gal.) of liquid wastes were applied per acre.

[16]Tractor/equipment hours were calculated as follows: .5 + [(X) x 1000 ft^3 of wastes applied]. (X) equaled .7 and .4674 for 60, 100 cow herds.

APPENDIX C

Table A.C1 Supply of Manure for 60 Cow Dairy

Type of Waste	Total Waste		Nitrogen	Phosphorus	Potassium
	(pounds)	(cubic feet)	....	(pounds)	....
Daily Haul					
60 days					
Cow	207000	3330	1026	184	684
Heifer	3375	149	45	8	32
Total manure	210375	3479	1071	192	716
Bedding	11160	372	0		
Parlor Waste	21300	342	0		
Runoff	21179	2832	-375	-19	-72
Total	**264014**	**7024**	**696**	**173**	**644**
Dry Stack					
120 days storage					
Cow	414000	6660	2052	367	1368
Heifer	6750	297	90	16	63
Total manure	420750	6957	2142	383	1431
Bedding	22320	744	0		
Parlor Waste	42600	684	0		
Runoff	42358	5664	-482	-48	-143
Total	**528028**	**14049**	**1660**	**335**	**1288**
Earthen Pit					
180 days storage					
Cow	621000	9990	3078	551	2052
Heifer	10125	446	135	24	95
Total Manure	631125	10436	3213	575	2147
Bedding	33480	1116	0		
Parlor Waste	63900	1026	0		
Runoff	529266	8496	-643	-72	-215
Emerg. Storm		3376			
Added Vol		16616	0	0	0
Total		**41065**	**2570**	**503**	**1932**
Lagoon					
180 days storage					
Cow	621000	9990	3078	551	2052
Heifer	10125	446	135	24	94.5
Total manure	631125	10436	3213	575	2146.5
Bedding	33480	1116	0		
Parlor Waste	63900	1026	0		
Runoff	529266	8496	-1607	-115	-322
Emerg. Storm		3376			
Min Vol		142800			
Dilution		71400	0	0	0
Total		**249085**	**1607**	**460**	**1825**

Table A.C2 Labor and Equipment for 60 Cow Dairy

	Labor Hours	Labor Cost	Labor Annual Hours	Labor Annual Cost	Equipment Hours	Equipment Cost	Equipment Annual Hours	Equipment Annual Cost	Tractor Fuel & Lub Cost
Daily Haul									
Daily Clean	41.1	205.32	246.4	1231.90	33.3	166.32	199.6	997.90	398.83
Loading	4.8	23.99	28.8	143.95	4.3	21.28	25.5	127.68	118.17
Hauling	12.5	62.59	75.1	375.54	11.5	57.59	69.1	345.54	316.65
Total	**58.4**	**291.90**	**350.3**	**1751.39**	**49.1**	**245.19**	**294.2**	**1471.12**	**833.65**
Dry Stack									
Daily clean	41.1	205.32	246.4	1231.90	33.3	166.32	199.6	997.90	398.83
Loading liq.	2.7	13.25	7.9	39.75	2.1	10.75	6.4	32.24	30.10
Loading solids	3.5	17.55	10.6	52.64	3.0	15.05	9.0	45.14	42.14
Hauling solids	19.1	95.73	57.4	287.19	18.1	90.73	54.4	272.19	254.05
Hauling liq.	9.6	48.08	28.8	144.25	9.6	48.08	28.8	144.25	134.63
Total	**76.0**	**379.93**	**351.1**	**1755.73**	**66.1**	**330.93**	**298.2**	**1491.72**	**859.75**
Earthen Pit/liq.haul									
Daily clean	41.1	205.32	246.4	1231.90	33.3	166.32	199.6	997.90	398.83
Agit/loading	43.9	219.62	87.8	439.24	10.9	54.78	21.9	109.55	102.25
Hauling	51.3	256.39	102.6	512.78	49.8	248.88	99.5	497.78	464.61
Total	**136.3**	**681.33**	**436.8**	**2183.92**	**94.0**	**469.98**	**321.0**	**1605.23**	**965.69**
Earthen Pit/Irrig.									
Daily clean	41.1	205.32	246.4	1231.91	33.3	166.32	199.6	997.90	398.83
Agitation	16.9	84.49	33.8	168.98	13.4	66.96	26.8	133.92	93.33
Irrigation	2.0	10.00	4.0	20.00	19.9	99.65	39.8	199.30	186.01
Total	**60.0**	**299.81**	**284.2**	**1420.89**	**66.6**	**332.93**	**266.2**	**1331.12**	**678.17**
Lagoon/liq.haul									
Daily clean	41.1	205.32	246.4	1231.90	33.3	166.32	199.6	997.90	398.83
Agit/loading	50.6	253.20	101.3	506.40	23.7	119.03	47.6	238.07	222.18
Hauling	62.0	310.11	124.0	620.23	112.1	560.37	224.1	1120.74	1046.03
Total	**153.7**	**768.63**	**471.7**	**2358.53**	**169.1**	**845.72**	**471.3**	**2356.71**	**1667.04**
Lagoon/Irrig.									
Daily clean	41.1	205.32	246.4	1231.90	33.3	166.32	199.6	997.90	398.83
Agitation	24.7	123.74	49.5	247.48	6.9	34.66	13.9	69.32	93.33
Irrigation	3.0	15.00	6.0	30.00	44.0	219.79	87.9	87.92	410.29
Total	**68.8**	**344.06**	**301.9**	**1509.38**	**84.2**	**420.77**	**301.4**	**1155.14**	**902.45**

Table A.C3 Initial Cost Budget for Manure Systems, 60 Cow Dairy

	Size	Initial Price	Life	Depreciation	Insurance, Repair,Tax	Insurance % Use	Annual Depreciation	Annual I/R/T
Daily Haul								
Scraper tractor	34 hp	11000	10	880	319	0.8	704	255.2
Frontend loader		4000	10	320	108.14	1	320	108.14
Boxscraper	6 ft	800	10	64	24.18	1	64	24.18
Boxspreader	175 bu	4477	8	447.7	164.73	1	447.70	164.73
Tractor for spreading	80 hp	25000	10	2000	697	0.1	200	69.70
Total		**45277**					**1735.70**	**621.95**
Per cow		**755**					**28.93**	**10.37**
Dry Stack								
Scraper tractor	34 hp	11000	10	880	319	0.8	704	255.2
Frontend loader		4000	10	320	108.14	1	320	108.14
Boxscraper	6 ft	800	10	64	24.18	1	64	24.18
Boxspreader	175 bu	4477	8	447.7	164.73	1	447.70	164.73
Pump pto	500gpm	3320	8	332	87.18	1	332	87.18
Liquid spreader	1000 gl	7400	5	1184	235.82	1	1184	235.82
Tractor for spreading	100 hp	35000	10	2800	975.36	0.1	280	97.54
Holding pond	7200 ft3	504	20	20	32.45	1	20.16	32.45
Dry stack	8841ft3	7961	20	318	95.53	1	318.44	95.53
Total		**74462**					**3670.30**	**1100.76**
Per cow		**1241**					**61.17**	**18.35**
Earthen Pit								
Scraper tractor	34 hp	11000	10	880	319	0.8	704	255.2
Frontend loader		4000	10	320	108.14	1	320	108.14
Boxscraper	6 ft	800	10	64	24.18	1	64	24.18
Pump agt/removal	2600 gpm	5000	8	500	129.18	1	500	129.18
Liquid spreader	1500 gl	8000	5	1280	250.82	1	1280	250.82
Tractor for agt.	100 hp	35000	10	2800	975.36	0.1	280	97.54
Tractor for spreading	100 hp	35000	10	2800	975.36	0.1	280	97.54
Earthen pit	41570 ft3	2909	20	116	29.09	1	116.36	29.09
Total		**101709**					**3544.36**	**991.68**
Per cow		**1695**					**59.07**	**16.53**

Table A.C3 (Continued)

	Size	Initial Price	Life	Depreciation	Insurance, Repair,Tax	Insurance % Use	Annual Depreciation	Annual I/R/T
Earthen Pit/BG								
Scraper tractor	34 hp	11000	10	880	319	0.8	704	255.2
Frontend loader		4000	10	320	108.14	1	320	108.14
Boxscraper	6 ft	800	10	64	24.18	1	64	24.18
Traveling big gun	660 ft	12375	8	1237.5	313.56	1	1237.5	313.56
Pump agt/removal	2600 gpm	5000	8	500	129.18	1	500	129.18
Mainline PVC	2000 ft	3760	10	300.8	98.18	1	300.8	98.18
Tractor pumping	100 hp	35000	10	2800	975.36	0.1	280	97.54
Tractor for agt.	100 hp	35000	10	2800	975.36	0.1	280	97.54
Irrigation pump	500 gpm	4000	8	400	104.18	1	400	104.18
Earthen pit	41570 ft3	2909	20	116.36	29.09	1	116.36	29.09
Total		**113844**					**4202.66**	**1256.78**
Per cow		**1897**					**70.04**	**20.95**
Single Stage Lagoon								
Scraper tractor	34 hp	11000	10	880	319	0.8	704	255.2
Frontend loader		4000	10	320	108.14	1	320	108.14
Boxscraper	6 ft	800	10	64	24.18	1	64	24.18
Pump pto	500gpm	3320	8	332	87.18	1	332	87.18
Liquid spreader	1500 gl	8000	5	1280	250.82	1	1280	250.82
Tractor for spreading	100 hp	35000	10	2800	975.36	0.1	280	97.54
Tractor for agt.	100 hp	35000	10	2800	975.36	0.1	280	97.54
Lagoon	250094 ft3	12212	20	488.48	172.94	1	488.48	172.94
Total		**109332**					**3748.48**	**1093.54**
Per cow		**1822**					**62.47**	**18.23**

Table A.C3 (Continued)

	Size	Initial Price	Life	Depreciation	Insurance, Repair,Tax	Insurance % Use	Annual Depreciation	Annual I/R/T
Lagoon/BG								
Scraper tractor	34 hp	11000	10	880	319	0.8	704	255.2
Frontend loader		4000	10	320	108.14	1	320	108.14
Boxscraper	6 ft	800	10	64	24.18	1	64	24.18
Traveling big gun	660 ft	12375	8	1237.5	313.56	1	1237.5	313.56
Pump agt/removal	2600 gpm	5000	8	500	129.18	1	500	129.18
Mainline PVC	2000 ft	3760	10	300.8	98.18	1	300.8	98.18
Tractor	100 hp	35000	10	2800	975.36	1	280	97.54
Tractor	100 hp	35000	10	2800	975.36	0.1	280	97.54
Irrigation pump	500 gpm	4000	8	400	104.18	1	400	104.18
Lagoon	250094 ft3	12212	20	488.48	172.944	1	488.48	172.94
Total		**123147**					**4574.78**	**1400.63**
Per cow		**2052.45**					**76.25**	**23.34**

Table A.C4 Net Annual Cost Budgets for Manure Systems, 60 Cow Dairy

System	Depreciation	I/R/T[1]	Labor	Energy	Manure Value	Net Annual Cost
Daily Haul	1736	622	1751	834	1963.32	2979.68
Dry Stack	3670	1101	1756	860	2164.29	5222.71
Earthen Pit	3544	992	2184	966	2206.14	5479.86
Earthen Pit/Irrig.	4203	1257	1421	678	2140	5419
Lagoon	3748	1094	2359	1667	1649	7219
Lagoon/Irrig.	4575	1401	1509	902	1600	6787

[1] Annual insurance, repair, and taxes

Table A.C5 Supply of Manure, 100 Cow Dairy

Type of Waste	Waste		Nitrogen	Phosphorus	Potassium
	(pounds)	(cubic feet)	....	(pounds)	....
Daily Haul					
60 days					
Cow	345000	5550	1710	306	1140
Heifer	9375	247.5	75	13.5	52.5
Total manure	354375	5797.5	1785	319.5	1192.5
Bedding	18600	620	0		
Parlor Waste	30300	486.36	0		
Runoff	50542	6755	-624.75	-31.95	-119.25
Total	**453817**	**13658.86**	**1160.25**	**287.55**	**1073.25**
Dry Stack					
120 days storage					
Cow	690000	11100	3420	612	2280
Heifer	18750	495	150	27	105
Total manure	708750	11595	3570	639	2385
Bedding	37200	1240	0		
Parlor Waste	60600	972.7	0		
Runoff	101084	13510	-803.25	-79.875	-238.5
Total	**907634**	**27317.7**	**2766.75**	**559.125**	**2146.5**
Earthen Pit					
180 days storage					
Cow	1035000	16650	5130	918	3420
Heifer	28125	743	225	40.5	157.5
Total Manure	1063125	17393	5355	958.5	3577.5
Bedding	55800	1860	0		
Parlor Waste	90900	1459	0		
Runoff	151662	20265	-1071	-119.81	-357.75
Emerg. Storm		17678			
Min Vol	0	16616	0	0	0
Total	**1361487**	**75270**	**4284**	**838.69**	**3219.75**
Lagoon					
180 days storage					
Cow	1035000	16650	5130	918	3420
Heifer	28125	743	225	40.5	157.5
Total manure	1063125	17393	5355	958.5	3577.5
Bedding	55800	1860	0		
Parlor Waste	90900	1459	0		
Runoff	1515462	202656	-2678	-191.7	-536.63
Emerg. storm		17678			
Min Vol		238000			
Dilution	0	119000	0	0	0
Total	**2725287**	**615438**	**2678**	**766.8**	**3040.87**

Table A.C6 Labor and Equipment Costs Budget for Manure Systems, 100 Cow Dairy

	Labor Hours	Labor Cost	Labor (annual hrs)	Labor (annual cost)	Equipment Hours	Equipment Cost	Equipment (annual hrs)	Equipment (annual cost)	Tractor Lube & Fuel Cost
Daily Haul									
Daily Clean	58.3	291.60	349.9	1749.39	50.5	252.57	303.1	1515.39	607.26
Loading	6.8	34.20	41.0	205.23	8.4	42.17	50.6	253.04	301.14
Hauling	29.0	144.80	173.8	869.06	23.3	116.62	139.9	699.73	957.61
Total	**94.1**	**470.60**	**564.7**	**2823.69**	**82.2**	**411.36**	**493.6**	**2468.18**	**1866.01**
Dry Stack									
Daily clean	58.3	291.57	349.9	1749.39	50.5	252.57	303.1	1515.39	607.26
Loading liq.	4.7	23.46	14.1	70.39	4.2	21.40	12.8	64.20	67.45
Loading solids	4.7	23.54	14.1	70.62	4.6	23.10	13.9	69.31	78.29
Hauling solids	27.6	137.92	82.8	413.76	26.6	132.92	79.8	398.76	475.79
Hauling liq.	16.5	82.41	49.4	247.23	19.4	96.89	58.1	290.68	349.31
Total	**111.8**	**558.90**	**510.3**	**2551.39**	**105.3**	**526.88**	**467.7**	**2338.34**	**1578.12**
Earthen Pit/liq.haul									
Daily clean	58.3	291.57	349.9	1749.39	50.5	252.55	303.1	1515.30	607.26
Agit/loading	57.6	287.89	115.1	575.78	27.4	136.90	54.8	273.80	331.25
Hauling	92.3	461.62	184.6	923.24	90.8	454.12	181.6	908.24	1370.17
Total	**208.2**	**1041.08**	**649.6**	**3248.41**	**168.7**	**843.57**	**539.5**	**2697.34**	**2308.68**
Earthen Pit/Irrig.									
Daily clean	58.3	291.57	349.9	1749.39	50.5	252.57	303.1	1515.39	607.26
Agitation	20.0	100.00	40.0	200.00	21.8	109.08	43.6	218.18	258.97
Irrigation	2.0	10.00	4.0	20.00	35.7	178.41	71.4	356.81	427.61
Total	**80.3**	**401.57**	**393.9**	**1969.39**	**108.0**	**540.06**	**418.1**	**2090.38**	**1293.85**
Lagoon/liq.haul									
Daily clean	58.3	291.57	349.9	1749.39	50.5	252.57	303.1	1515.39	607.26
Agit/loading	93.4	467.20	186.9	934.41	93.4	467.20	186.9	934.42	1120.22
Hauling	149.7	748.53	299.4	1497.06	230	1149.91	459.9	2299.82	3455.53
Total	**301.4**	**1507.30**	**836.2**	**4180.86**	**373.9**	**1869.68**	**949.9**	**4749.63**	**5183.02**
Lagoon/Irrig.									
Daily clean	58.3	291.57	349.9	1749.39	50.5	252.57	303.1	1515.39	607.26
Agitation	23.0	115.00	46.0	230.00	16.7	83.45	33.4	166.91	198.75
Irrigation	6.0	30.00	12.0	60.00	58	290.16	116.0	232.12	558.91
Total	**87.3**	**436.57**	**407.9**	**2039.39**	**125.2**	**626.18**	**452.5**	**2262.61**	**1364.92**

Table A.C7 Initial Cost Budget for Manure Systems, 100 Cow Dairy

Equipment	Size	Initial Price	Life	Depreciation	Insurance, Repair,Tax	% Use	Annual Depreciation	Annual I/R/T
Daily Haul								
Scraper tractor	34 hp	11000	10	880	319	0.8	704	255.2
Frontend loader		4000	10	320	108	1	320	108.14
Boxscraper	6 ft	800	10	64	24	1	64	24.18
Boxspreader	287 bu	7300	8	730	235	1	730	235.3
Tractor for spreading	100 hp	35000	10	2800	967	0.1	280	96.7
Total		**58100**					**2098**	**719.52**
Per cow		**968**					**34.97**	**11.99**
Dry Stack								
Scraper tractor	34 hp	11000	10	880	319	0.8	704	255.2
Frontend loader		4000	10	320	108	1	320	108.14
Boxscraper	6 ft	800	10	64	24	1	64	24.18
Boxspreader	287 bu	7300	8	730	235	1	730	235.3
Pump pto	500gpm	3320	8	332	87	1	332	87.18
Liquid spreader	1500 gl	9800	5	1568	298	1	1568	298.02
Tractor for spreading	100 hp	35000	10	2800	975	0.1	280	97.536
Holding pond	14500 ft3	1015	20	41	39	1	40.6	38.58
Dry stack	13000 ft3	11706	20	468	140	1	468.24	140.472
Total		**83941**					**4506.84**	**1284.60**
Per cow		**839**					**45.07**	**12.85**
Earthen Pit								
Scraper tractor	34 hp	11000	10	880	319	0.8	704	255.2
Frontend loader		4000	10	320	108	1	320	108.14
Boxscraper	6 ft	800	10	64	24	1	64	24.18
Pump agt/removal	2600 gpm	5000	8	500	129	1	500	129.18
Liquid spreader	2200 gl	12000	5	1920	351	1	1920	350.82
Tractor for spreading	125 hp	45000	10	3600	1245	0.1	360	124.536
Tractor for agt.	100 hp	35000	10	2800	975	0.1	280	97.536
Earthen pit	76000 ft3	5320	20	213	53	1	212.8	53.2
Total		**118120**					**4360.8**	**1142.79**
Per cow		**1969**					**72.68**	**19.05**

Table A.C7 (Continued)

Equipment	Size	Initial Price	Life	Depreciation	Insurance, Repair,Tax	% Use	Annual Depreciation	Annual I/R/T
Earthen Pit/Irrig.								
Scraper tractor	34 hp	11000	10	880	319	0.8	704	255.2
Frontend loader		4000	10	320	108	1	320	108.14
Boxscraper	6 ft	800	10	64	24	1	64	24.18
Traveling big gun	1100 ft	22666	8	2267	570	1	2266.6	570.83
Pump agt/removal	2600 gpm	5000	8	500	129	1	500	129.18
Mainline PVC	2000 ft	4736	10	379	122	1	378.88	122.58
Tractor pumping	100 hp	35000	10	2800	975	0.1	280	97.536
Tractor for agt.	100 hp	35000	10	2800	975	0.1	280	97.536
Irrigation pump	500 gpm	4000	8	400	104	1	400	104.18
Earthen pit	76000 ft3	5320	20	213	53	1	212.8	53.2
Total		**127522**					**5406.28**	**1562.56**
Per cow		**2125**					**90.10**	**26.04**
Single Stage Lagoon								
Scraper tractor	34 hp	11000	10	880	319	0.8	704	255.2
Frontend loader		4000	10	320	108	1	320	108.14
Boxscraper	6 ft	800	10	64	24	1	64	24.18
Pump pto	500gpm	3320	8	332	87	1	332	87.18
Liquid spreader	2200 gl	12000	5	1920	351	1	1920	350.82
Tractor for spreading	125 hp	45000	10	3600	1245	0.1	360	124.54
Tractor for agt.	100 hp	35000	10	2800	975	0.1	280	97.54
Lagoon	615000 ft3	24600	20	984	322	1	984	321.6
Total		**135720**					**4964**	**1369.19**
Per cow		**2262**					**82.73**	**22.82**

Table A.C7 (Continued)

Equipment	Size	Initial Price	Life	Depreciation	Insurance, Repair,Tax	% Use	Annual Depreciation	Annual I/R/T
Lagoon/Irrig.								
Scraper tractor	34 hp	11000	10	880	319	0.8	704	255.2
Frontend loader		4000	10	320	108	1	320	108.14
Boxscraper	6 ft	800	10	64	24	1	64	24.18
Traveling big gun	1100 ft	22666	8	2267	571	1	2266.6	570.83
Pump agt/removal	2600 gpm	5000	8	500	129	1	500	129.18
Mainline PVC	2000 ft	4736	10	379	123	1	378.88	122.58
Tractor pumping	100 hp	35000	10	2800	975	0.1	280	97.536
Tractor for agit.	100 hp	35000	10	2800	975	0.1	280	97.536
Irrigation pump	500 gpm	4000	8	400	104	1	400	104.18
Lagoon	615000 ft3	24600	20	984	322	1	984	321.6
Total		**146802**					**6177.48**	**1830.96**
Per cow		**2447**					**102.96**	**30.52**

Table A.C8 Net Annual Cost Budget for Manure Systems, 100 Cow Dairy

System	Depreciation	I/R/T	Labor	Energy	Manure value	Net annual cost
Daily Haul	2098	720	2824	1866	3272	4236
Dry Stack	4507	1285	2551	1578	3608	6313
Earthen Pit	4360	1142	3248	2308	3677	7381
Earthen Pit/Irrigation	5406	1563	1969	1294	3568	6664
Lagoon	4964	1369	4180	5183	2749	12947
Lagoon/Irrig.	6177	1831	2039	1365	2667	8745

Table A.C9 Dairy Manure Production by Dairy Cattle

	Total Manure Production				Density	Nutrient Content (#/day)
Size lbs.	lb/day	ft2/day	gal/day	% Water	lb/ft3	N
150	12	0.19	1.5	87.3	62	0.06
250	20	0.32	2.4	87.3	62	0.1
500	41	0.66	5	87.3	62	0.2
1000	82	1.32	9.9	87.3	62	0.41
1400	115	1.85	13.9	87.3	62	0.57

Source: Livestock Waste Facilities Handbook

Table A.C10 Dairy Production of Milking Parlor Wastes by Herd Size

Parlor Waste Source	Daily Waste Production (Gallons)	
	60 Cows (gal)	100 Cows (gal)
Bulk Tank	80	80
Pipeline	100	200
Udder Wash	60	100
Parlor Floor	75	75
Milkhouse Floor	10	20
Miscellaneous	30	30
	355	505

Source: Livestock Waste Facilities Handbook

Table A.C11 Nutrient Loss for Each Manure System

	Nitrogen	Phosphorus	Potassium
Solid/			
Daily Haul	30-40	5-15	5-15
Dry Stack	15-30	5-20	5-15
Slurry/			
Earthen Pit	15-25	5-20	5-15
Liquid/			
Single Stage Lagoon	40-60	10-30	5-25

Source: Livestock Waste Facilities Handbook

Table A.C12 Nitrogen Lost at Ground Surface as Free Ammonia, by Soil Moisture/Temperature Type.

Days Between Application and Incorporation	Nitrogen Loss (%)		
	Warm Dry Soil	Warm Moist Soil	Cool Moist Soil
1	30	10	0
4	40	20	5
7 or more	50	30	10

Source: Livestock Waste Facilities Handbook

APPENDIX D

Table A.D1 Example of Feed Transfer Nutrient Coefficient Development

Feeding Corn Silage

1 ton corn silage = 2000 pounds

Nutrient Requirements (NRC) Values:

DM %	= 35		
Prot %	= .08	Ck = .4536	
NEl	= 1.59	Ck = .4536	

Crude Protein Coefficient = (2000) * (.35) * (.08) * (.4536) = 25.40 Kg/ton

NE Coefficient = (2000) * (.35) * (1.59) * (.4536) = 504.85 Mcal/ton

Crop	Item	Amount	Protein Supplied	Net Energy Supplied
Corn Silage	DM	0.35	25.40	504.86
	Protein	0.08		
	NEm	1.54		
	NEl	1.59		
Alfalfa	DM	0.89	129.19	1009.26
	Protein	0.16		
	NEm	1.19		
	NEl	1.25		
Corn	DM	0.87	2.06	40.66
	Protein	0.093		
	NEm	1.86		
	NEl	1.84		
Pasture	DM	0.28	31.50	355.62
	Protein	0.124		
	NEm	1.33		
	NEl	1.4		
Hay	DM	0.88	83.83	981.96
	Protein	0.105		
	NEm	1.17		
	NEl	1.23		
Rye	DM	0.28	32.01	299.74
	Protein	0.126		
	NEm	1.13		
	NEl	1.18		
Wheat	DM	0.26	28.07	330.22
	Protein	0.119		
	NEm	1.33		
	NEl	1.40		

Source: Nutrient Requirements of Dairy Cattle (The National Research Council) Resource Conservation Act Analysis

Table A.D2 List of Farm Input and Output Prices

Item	Price	Cost	Units
Dairy			
Milk	13.00	-	cwt
Alfalfa	99.99	-	ton
Fescue Hay	49.99	-	ton
Rep Heifer	983.00	-	head
Cull cow	625.00	-	head
Corn	3.00	-	bushel
Calf	85.00	-	head
Rented Land	-	-	
Land type 1	-	50.00	acre
Land type 2	-	35.00	acre
Hired Labor	-	5.00	hour
Fertilizer	-	-	
Nitrogen	-	0.26	lb
Phosphorus	-	0.25	lb
Potassium	-	0.16	lb
Concentrate	-	160.00	ton

Table A.D3 Cost of Production

Enterprise	Dollars
Dairy	827.00
Replacement Heifer	643.00
Pasture	33.00
Corn Silage/Rye	213.00
Corn Silage/Wheat	213.00
Corn Silage	126.00
Fescue Hay	62.00
Alfalfa	162.00

Table A.D4 Yield Per Acre for the Three Land Types

Crop	Units	Land Type 1	Land Type 2	Land Type 3
Pasture	ton	2.4	2.2	2
Corn	bu	93		
Corn Silage	ton	18		
Rye	ton	4		
Wheat	ton	5		
Fescue Hay	ton	3	2.7	2.5
Alfalfa Hay	ton	3	3	

Source: Big Limestone Survey

Table A.D5 Nitrogen Loss for Each Crop and Time Period

Crop	Land Type*	Time Period**	Sur Leach	Sub Leach	Leach	Total	Fertilizer	Ratio Nitrogen Loss
					(pounds per acre)			
Alfalfa	1	1	2	2	11	15	***	0.1
Alfalfa	1	2	2	2	10	14	***	0.1
Alfalfa	1	6	2	2	10	14	***	0.1
Alfalfa	2	1	3	3	9	15	***	0.1
Alfalfa	2	2	3	2	7	12	***	0.1
Alfalfa	2	6	3	2	7	12	***	0.1
Hay	1	1	2	3	30	35	49	0.71
Hay	1	2	0	3	14	17	49	0.35
Hay	1	5	0	3	14	17	49	0.35
Hay	1	6	0	3	14	17	49	0.35
Hay	2	1	2	5	28	35	49	0.71
Hay	2	2	1	4	12	17	49	0.35
Hay	2	5	1	4	18	23	49	0.47
Hay	2	6	1	4	23	28	49	0.57
Hay	3	1	3	8	24	35	49	0.71
Hay	3	2	1	6	9	16	49	0.33
Hay	3	5	1	4	18	23	49	0.47
Hay	3	6	1	6	20	27	49	0.55
Corn	1	1	0	8	79	87	113	0.77
Corn	1	2	3	6	43	52	113	0.46
Corn	1	6	1	6	80	87	113	0.77
Corn Silage	1	1	13	8	63	84	151	0.56
Corn Silage	1	1	13	8	63	84	170	0.49
Corn Silage	1	1	3	7	90	100	113	0.88
Corn Silage	1	2	4	8	57	69	113	0.61
Corn Silage	1	6	3	7	94	104	113	0.92
Pasture	1	1	0	2	10	12	48	0.25
Pasture	1	2	0	2	10	12	48	0.25
Pasture	1	3	0	2	10	12	48	0.25
Pasture	1	4	0	2	10	12	48	0.25
Pasture	1	5	0	2	10	12	48	0.25
Pasture	1	6	0	2	10	12	48	0.25
Pasture	2	1	1	3	11	15	48	0.25
Pasture	2	2	1	3	11	15	48	0.31
Pasture	2	3	1	4	10	15	48	0.31
Pasture	2	4	1	3	11	15	48	0.31
Pasture	2	5	1	4	10	15	48	0.31
Pasture	2	6	1	4	10	15	48	0.31
Pasture	3	1	1	4	9	14	48	0.29
Pasture	3	2	1	4	9	14	48	0.29
Pasture	3	3	1	4	9	14	48	0.29
Pasture	3	4	1	4	9	14	48	0.29
Pasture	3	5	1	4	9	14	48	0.29
Pasture	3	6	1	4	9	14	48	0.29

*Land type that crop is grown on.
**Time period that nitrogen was applied.
***No nitrogen fertilizer applied.

Table A.D6 Labor Requirements for Crops and Livestock

	Jan-Feb.	March-April	May-June	July-Aug.	Sept.-Oct	Nov.-Dec.	Total
				Hours			
Corn		0.53	1.44		0.82	0.20	2.99
Corn Silage		0.53	1.21		3.80		5.33
Wheat Silage			3.21		0.75	0.29	4.25
Rye Silage			3.21		0.75	0.29	4.25
Alfalfa			5.41	2.90	2.59		10.89
Pasture			0.90	1.13			2.03
Fescue Hay			2.92	2.92			5.84
Dairy Cow 60	10.13	10.30	9.68	9.77	9.75	10.37	60.00
Dairy Cow 100	8.44	8.58	8.07	8.14	8.12	8.65	50.00
Replacement Heifer	5.52	4.52	2.48	1.52	1.20	1.28	16.52

Table A.D7 Production Cost for Corn

Item	Description	Unit	Quantity	Price	Amount
Revenue					
Corn	Grain	bu	90.00	2.30	207.00
				Total Revenue	**207.00**
Variable Expenses					
Seed	10-20	thousand	21.00	1.00	21.00
Fertilizer	n	lbs	90	.26	22.50
	P_2O_5	lbs	50	.25	12.50
	K_2O	lbs	50	.16	8.00
Lime		ton	.5	14.00	7.00
Weed Control					
Atrazine	4#/gal	qt	1.25	3.05	3.81
Lasso	4#/gal	qt	2.00	5.08	10.16
Machinery		ac	1.00	33.70	33.70
				Total Variable Expenses	**119.67**
				Return Above Variable Expenses	**88.33**

Table A.D8 Production Cost for Corn Silage

Item	Description	Unit	Quantity	Price	Amount
Revenue					
Silage	65-70% moisture	ton	17	22	374.00
				Total Revenue	**374.00**
Variable Expenses					
Seed	18-20	thousand	20.00	1.00	20.00
Fertilizer	n	lbs	100	.26	26.00
	P_2O_5	lbs	60	.25	15.00
	K_2O	lbs	120	.16	19.20
Lime		ton	.5	14.00	7.00
Weed Control					
Atrazine	4#/gal	qt	1.25	3.05	3.81
Lasso	4#/gal	qt	1.75	5.08	8.88
Machinery		ac	1.00	52.40	52.40
				Total Variable Expenses	**152.30**
				Return Above Variable Expenses	**219.70**

Table A.D9 Production Cost for Wheat/Rye

Item	Description	Unit	Quantity	Price	Amount
Revenue					
Silage	60-65% moisture	ton	6	25.00	150.00
				Total Revenue	**150.00**
Variable Expenses					
Seed		bu	1.5	9.00	13.50
Fertilizer	n	lbs	60	.26	15.60
	P_2O_5	lbs	40	.25	10.00
	K_2O	lbs	40	.16	6.40
Lime		ton	.4	14.00	75.60
Machinery		ac	1.00	44.47	44.47
				Total Variable Expenses	**95.57**
				Return Above Variable Expenses	**54.43**

Table A.D10 Production Costs for Fescue Hay

Item	Description	Unit	Quantity	Price	Amount
Revenue					
Hay	2 cutting/year	ton	2.5	60.00	150.00
				Total Revenue	**150.00**
Variable Expenses					
Establishment Cost	10 years prorated				10.09
Fertilizer	n	lbs	60	.26	15.60
	P_2O_5	lbs	45	.25	11.25
	K_2O	lbs	45	.16	7.20
Twine		bale	8.30	.05	.42
Machinery		ac	1.00	32.69	32.69
				Total Variable Expenses	**77.25**
				Return Above Variable Expenses	**72.75**

Table A.D11 Production Costs for Alfalfa Hay

Item	Description	Unit	Quantity	Price	Amount
Revenue					
Alfalfa		ton	3.5	100.00	350.00
				Total Revenue	**350.00**
Variable Expenses					
Establishment Cost	4 years prorated				43.91
Fertilizer	P_2O_5	lbs	50.00	.25	12.00
	K_2O	lbs	150.00	.16	24.00
Boron		lbs	2.00	2.38	4.76
Insect Control		qt	1.00	14.39	14.39
Twine		bale	.40	.05	7.00
Machinery Fuel		ac	1.00	17.76	17.76
Machinery Repair		ac	1.00	38.54	38.54
				Total Variable Expenses	**162.36**
				Return Above Variable Expenses	**187.64**

Table A.D12 Production Costs for Replacement Heifers

Item	Description	Unit	Quantity	Price	Amount
Revenue					
Heifer	1,100	head	1	1,000.00	1,000.00
Death Loss	5% calf 2% yearling				-4.25 -12.00
				Total Revenue	**983.75**
Variable Expenses					
Calf	2-3 days old	head	1	85.00	85.00
Milk Replacer		cwt	.90	60.00	54.00
Calf Starter		cwt	.90	13.00	11.70
Concentrate	14% growing ration	cwt	6.75	10.80	72.90
Alfalfa Hay		ton	.37	100.00	37.00
Hay	grass & clover hay	ton	1.80	60.00	108.00
Pasture		acre	1.50	92.52	138.78
Salt & Minerals		head	1.00	3.01	3.01
Vet and Med		head	1.00	87.30	87.30
Breeding		head	1.00	15.00	15.00
Bedding		head	1.00	18.76	18.76
Marketing & Trucking		head	1.00	9.00	9.00
Machinery		hr.	.80	2.57	2.06
				Total Variable Expenses	77.25
				Return Above Variable Expenses	72.75

Table A.D13 Production Costs for Permanent Pasture

Item	Description	Unit	Quantity	Price	Amount
Expenses					
Establishment Cost prorated 10 Years					10.09
Fertilizer	n	lbs	.60	.26	15.60
	P_2O_5	lbs	.30	.25	7.50
	k_2O	lbs	.30	.16	4.80
Lime		ton	.20	14.00	2.80
Machinery	Fuel	ac	1.00	7.96	7.96
			Total Variable Expenses		**48.75**

Table A.D14 Production Costs for Dairy Cow

Item	Description	Unit	Quantity	Price	Amount
Revenue					
Milk	15,000 lbs/cow	cwt		13.00	1,950.00
Calves	2-3 days old	head		85.00	38.25
Cull Cows	25% cull rate	head		625.00	156.25
Heifers	yearlings	head		700.00	23.33
				Total Revenue	**2,167.83**
Variable Expenses					
Dairy Feed	2.5 concentrate	ton	160.00		400.00
Silage Corn	11/cow	ton	25.00		275.00
Alfalfa	1.5/cow	ton	100.00		150.00
Pasture	1.5 acre	acre	46.26		69.39
Salt		cwt	13.30		1.99
Mineral Supplement		cwt	12.37		3.71
Milk Replacer	all milk	cwt	60.00		7.50
Calf Starter		cwt	13.00		5.85
Breeding Fees	artificial	head	18.50		22.20
DHIA dues		head	18.00		18.00
Milk Hauling		cwt	.85		127.50
Vet and Med		head	.30		30.00
Dairy Supplies		head	28.00		28.00
Bedding			20.00		20.00
Electricity		kwh	.06		45.00
Marketing Fees		head	8.25		1.93
Trucking Fees		head			1.28
Machinery		hr.	2.57		19.28
				Total Variable Expenses	**1,226.63**
				Return Above Variable Expenses	**941.20**

APPENDIX E

Greene county - Dunmore soil 11:05 20 June 92

```
thcnsldm.dat
WEAT: 107   TN  KNOXVILLE   WI:   87   NC  BUNCOMBE          SOIL: 201
DUNMORE         B
 30   1   1   1  51   0   0   0   0   1   0   1   2
   1.00    81.0            .1500   .0350   .1500     1.0   36.00   366.0      .0
     .8    25.0   330.0      .0
   46.0   .0800    1.00      2.
   45.1    91.7     8.0      .0      .0
  9.89 11.39 15.83 21.56 26.11 30.56 31.72 31.00 28.61 22.50 15.06 10.17
  -.50   .22  3.50  8.44 13.22 18.06 19.78 18.94 15.89  8.94  3.11  -.17
  4.48  4.38  4.52  3.66  2.79  2.47  2.45  3.46  3.05  3.54  4.11  4.41
  7.75  7.02  5.48  3.99  3.59  3.71  2.57  4.17  4.00  3.97  5.38  6.06
 113.9 117.3 128.6  99.4  79.2  99.5 103.4  82.4  71.3  64.2  92.5 118.9
  11.9  11.7  13.5  10.4   8.4  11.4  11.9  12.2  10.4  10.9  11.7  15.0
  3.16  1.79  2.59  2.26  1.74  1.87  3.71  3.38  2.03  2.66  2.27  3.12
  .317  .329  .327  .294  .253  .291  .304  .257  .191  .170  .271  .289
  .506  .531  .506  .528  .473  .444  .494  .422  .477  .503  .467  .466
 12.12 11.54 12.35 11.51 10.06 10.31 11.63  9.54  8.03  7.90 10.11 10.89
   7.1  10.7  15.7  24.1  31.2  28.4  32.0  20.3  18.3  13.2  12.7  15.7
  161.  239.  331.  450.  518.  551.  526.  478.  416.  318.  213.  163.
   .74   .72   .74   .69   .71   .70   .74   .76   .74   .74   .72   .72
     .00     .00     .00     .00
     .50   80.00     .00
  4.02  4.02  4.47  4.47  3.58  3.13  3.13  2.68  2.68  2.68  3.13  3.58
   7.0    .0   5.0   4.0   4.0   5.0   5.0   6.0   7.0   6.0   5.0   6.0
   7.0   6.0   6.0   5.0   5.0   5.0   5.0   5.0   6.0   6.0   5.0   5.0
  16.0  18.0  16.0  13.0  12.0  12.0  13.0  13.0  16.0  20.0  15.0  17.0
   6.0   6.0   6.0   5.0   6.0   7.0   7.0   7.0   7.0   7.0   7.0   7.0
   3.0   3.0   3.0   3.0   3.0   4.0   3.0   5.0   7.0   3.0   2.0   4.0
   1.0   2.0   2.0   2.0   2.0   2.0   2.0   2.0   2.0   2.0   3.0   2.0
   2.0   3.0   2.0   2.0   2.0   3.0   3.0   3.0   3.0   1.0   3.0   3.0
   1.0   1.0   1.0   1.0   2.0   1.0   2.0   2.0   2.0   2.0   1.0   2.0
   3.0   3.0   3.0   3.0   3.0   4.0   3.0   4.0   4.0   4.0   4.0   3.0
   3.0   3.0   3.0   5.0   5.0   4.0   4.0   3.0   3.0   3.0   4.0   3.0
  13.0  12.0  13.0  18.0  16.0  16.0  13.0   9.0   7.0   8.0  12.0  12.0
  11.0  10.0  12.0  13.0  12.0  10.0   9.0   7.0   6.0   7.0   9.0  10.0
   9.0   9.0   9.0   9.0   8.0   9.0   8.0   8.0   6.0   7.0   9.0   9.0
   4.0   4.0   7.0   4.0   4.0   3.0   4.0   4.0   3.0   3.0   4.0   4.0
   4.0   4.0   4.0   4.0   4.0   3.0   4.0   5.0   3.0   4.0   4.0   4.0
   2.0   2.0   2.0   2.0   2.0   2.0   2.0   2.0   2.0   2.0   2.0   2.0
    .18      0.     .00       0     .00     .00     .00     .00      0.      0.
   .010    .150    .180    .330    .560    .710   1.110   1.510
  1.400   1.400   1.400   1.450   1.450   1.500   1.550   1.550
```

.129	.129	.129	.287	.354	.337	.324	.324		
.254	.254	.254	.384	.451	.425	.407	.407		
39.7	39.7	39.7	16.6	9.5	8.6	6.7	6.7		
42.2	42.2	42.2	25.2	16.3	15.7	18.6	18.6		
400.	400.	400.	51.	51.	42.	42.	29.	22.	22.
5.6	5.6	5.6	5.2	5.3	5.2	5.1	5.1		
1.4	1.4	1.4	2.3	2.6	3.6	1.6	1.6		
.80	.80	.80	.10	.10	.08	.08	.06	.06	.06
5.8	5.8	5.8	7.5	7.8	9.8	9.7	9.7		
10.	10.	5.	5.	5.	5.	5.	5.		
	30.	10.	10.	10.	10.	10.	10.		
.034	.434	.366	.395	.266	.085	.020	.020		
1.50	1.50	1.50	1.55	1.55	1.60	1.66	1.66		

1 00 0 0 0 0 0 0

.00 .00 .00 .00 .00 .00 .00 .00 .00 .00

4 13 71 127.00 103.00 96.00

5 11 41

5 12 30

5 13 29

5 14 11 38 1.00 4.20

5 14 29

5 15 2 75 1750.00

9 20 53

```
$    title dairy 60 system 1
$    offupper
*    This program will evaluate imposed waste management systems effects on farm income
*    Definition of variables:
*    RTL1 IS LAND TYPE1 CONSTRAINT (UNITS ARE IN ACRES)
*    RTL2 IS LAND TYPE2 CONSTRAINT (UNITS ARE IN ACRES)
*    RTL3 IS LAND TYPE3 CONSTRAINT (UNITS ARE IN ACRES)
*    RFL1 IS FAMILY LABOR IN TIME PERIOD 1 CONSTRAINT (UNITS ARE HOURS)
*    RFL2 IS FAMILY LABOR IN TIME PERIOD 2 CONSTRAINT (UNITS ARE HOURS)
*    RFL3 IS FAMILY LABOR IN TIME PERIOD 3 CONSTRAINT (UNITS ARE HOURS)
*    RFL4 IS FAMILY LABOR IN TIME PERIOD 4 CONSTRAINT (UNITS ARE HOURS)
*    RFL5 IS FAMILY LABOR IN TIME PERIOD 5 CONSTRAINT (UNITS ARE HOURS)
*    RFL6 IS FAMILY LABOR IN TIME PERIOD 6 CONSTRAINT (UNITS ARE HOURS)
*    RHL1 IS HIRED LABOR IN TIME PERIOD 1 CONSTRAINT  (UNITS ARE HOURS)
*    RHL2 IS HIRED LABOR IN TIME PERIOD 2 CONSTRAINT  (UNITS ARE HOURS)
*    RHL3 IS HIRED LABOR IN TIME PERIOD 3 CONSTRAINT  (UNITS ARE HOURS)
*    RHL4 IS HIRED LABOR IN TIME PERIOD 4 CONSTRAINT  (UNITS ARE HOURS)
*    RHL5 IS HIRED LABOR IN TIME PERIOD 5 CONSTRAINT  (UNITS ARE HOURS)
*    RHL6 IS HIRED LABOR IN TIME PERIOD 6 CONSTRAINT  (UNITS ARE HOURS)
*    RNTS1 IS TRANSFER OF NITROGEN FROM WASTE MANAGEMENT SYSTEM TO CROP
     ACTIVITY IN TIME PERIOD 1 (UNITS ARE IN LBS)
*    RNTS2 IS TRANSFER OF NITROGEN FROM WASTE MANAGEMENT SYSTEM TO CROP
     ACTIVITY IN TIME PERIOD 2 (UNITS ARE IN LBS)
*    RNTS3 IS TRANSFER OF NITROGEN FROM WASTE MANAGEMENT SYSTEM TO CROP
     ACTIVITY IN TIME PERIOD 3 (UNITS ARE IN LBS)
*    RNTS4 IS TRANSFER OF NITROGEN FROM WASTE MANAGEMENT SYSTEM TO CROP
     ACTIVITY IN TIME PERIOD 4 (UNITS ARE IN LBS)
*    RNTS5 IS TRANSFER OF NITROGEN FROM WASTE MANAGEMENT SYSTEM TO CROP
     ACTIVITY IN TIME PERIOD 5 (UNITS ARE IN LBS)
*    RNTS6 IS TRANSFER OF NITROGEN FROM WASTE MANAGEMENT SYSTEM TO CROP
     ACTIVITY IN TIME PERIOD 6 (UNITS ACRE IN LBS)
*    RMT1 IS TRANSFER OF MANURE FROM LIVESTOCK ACTIVITY TO WASTE SYSTEM
     IN TIME PERIOD 1 (UNITS ARE IN LBS)
*    RMT2 IS TRANSFER OF MANURE FROM LIVESTOCK ACTIVITY TO WASTE SYSTEM
     IN TIME PERIOD 2 (UNITS ARE IN LBS)
*    RMT3 IS TRANSFER OF MANURE FROM LIVESTOCK ACTIVITY TO WASTE SYSTEM
     IN TIME PERIOD 3 (UNITS ARE IN LBS)
*    RMT4 IS TRANSFER OF MANURE FROM LIVESTOCK ACTIVITY TO WASTE SYSTEM
     IN TIME PERIOD 4 (UNITS ARE IN LBS)
*    RMT4 IS TRANSFER OF MANURE FROM LIVESTOCK ACTIVITY TO WASTE SYSTEM
     IN TIME PERIOD 5 (UNITS ARE IN LBS)
*    RMT6 IS TRANSFER OF MANURE FROM LIVESTOCK ACTIVITY TO WASTE SYSTEM
     IN TIME PERIOD 6 (UNITS ARE IN LBS)
*    RMKT IS MILK TRANSFER ROW (UNITS ARE  IN CWT.)
*    ROCT IS CONCENTRATE TRANSFER ROW (UNITS ARE TON)
*    RCFT IS BULL CALF TRANSFER ROW   (UNITS ARE PER HEAD)
*    RCOC IS NUMBER OF COW CONSTRAINT (UNITS ARE PER HEAD)
*    RCCT IS CULL COW TRANSFER ROW  (UNITS ARE PER HEAD)
*    RRCH1 IS NUMBER OF HEIFER CONSTRAINT (UNITS ARE PER HEAD)
*    RPNT IS PASTURE NITROGEN REQUIREMENT TRANSFER ROW (UNITS ARE IN LBS
     OF NITROGEN)
```

* RCNNT IS CORN NITROGEN REQUIREMENT TRANSFER ROW (UNITS ARE IN LBS OF NITROGEN)
* RCSLRNT IS CORN SILAGE/RYE NITROGEN REQUIREMENTS TRANSFER ROW (UNITS ARE IN LBS OF NITROGEN)
* RCSLWNT IS CORN SILAGE/WHEAT NITROGEN REQUIREMENTS TRANSFER ROW (UNITS ARE IN LBS OF NITROGEN)
* RCSLNT IS CORN SILAGE NITROGEN REQUIREMENTS TRANSFER ROW (UNITS ARE IN LBS OF NITROGEN)
* RHYNT IS HAY NITROGEN REQUIREMENTS TRANSFER ROW (UNITS ARE IN LBS OF NITROGEN)
* RAFNT IS ALFALFA NITROGEN REQUIREMENTS TRANSFER ROW (UNITS ARE IN LBS OF NITROGEN)
* RPRT IS PROTEIN REQUIREMENTS FOR LIVESTOCK ACTIVITY (I) (UNITS ARE IN LBS OF CRUDE PROTEIN)
* RNET IS NET ENERGY REQUIREMENTS FOR LIVESTOCK ACTIVITY (I) (UNITS ARE IN mcal)
* RPPT IS PASTURE PROTEIN REQUIREMENTS FOR HEIFERS (UNITS ARE ACRES)
* RPNET IS PASTURE NET ENERGY REQUIREMENTS FOR HEIFERS (UNITS ARE ACRES)
* RNO3 IS MAXINUN AMOUNT OF NITROGEN LOSS ALLOWABLE FOR A DAIRY FARM. (UNITS ARE LBS OF NITROGEN LOSS)
* FC8 IS THE FEED CONVERSION OF CORN (UNITS ARE BUSHEL
* XLA1 IS THE ACTIVITY LEVEL OF COWS (UNITS ARE PER HEAD)
* XLA2 IS THE ACTIVITY LEVEL OF HEIFERS (UNITS ARE PER HEAD)
* XCA1 IS THE ACTIVITY LEVEL OF PASTURE1 (UNITS ARE IN ACRES)
* XCA2 IS THE ACTIVITY LEVEL OF PASTURE2 (UNITS ARE IN ACRES)
* XCA3 IS THE ACTIVITY LEVEL OF PASTURE3 (UNITS ARE IN ACRES)
* XCA4 IS THE ACTIVITY LEVEL OF CORN (UNITS ARE IN ACRES)
* XCA5 IS THE ACTIVITY LEVEL OF CORN SILAGERYE (UNITS ARE IN ACRES)
* XCA6 IS THE ACTIVITY LEVEL OF CORN SILAGEWHEAT (UNITS ARE IN ACRES)
* XCA7 IS THE ACTIVITY LEVEL OF CORN SILAGE (UNITS ARE IN ACRES)
* XCA8 IS THE ACTIVITY LEVEL OF HAY1 (UNITS ARE IN ACRES)
* XCA9 IS THE ACTIVITY LEVEL OF HAY2 (UNITS ARE IN ACRES)
* XCA10 IS THE ACTIVITY LEVEL OF HAY3 (UNITS ARE IN ACRES)
* XCA11 IS THE ACTIVITY LEVEL OF ALFALFA1 (UNITS ARE IN ACRES)
* XCA12 IS THE ACTIVITY LEVEL OF ALFALFA2 (UNITS ARE IN ACRES)
* XSC1 IS THE ACTIVITY LEVEL OF SELLING ALFALFA (UNITS ARE IN TONS)
* XSC2 IS THE ACTIVITY LEVEL OF SELLING HAY (UNITS ARE IN TONS)
* XSC3 IS THE ACTIVITY LEVEL OF SELLING CORN (UNITS ARE IN BUSHELS)
* XBC1 IS THE ACTIVITY LEVEL OF BUYING CORN (UNITS ARE IN BUSHELS)
* XBC2 IS THE ACTIVITY LEVEL OF BUYING CONCENTRATE (UNITS ARE IN TONS)
* XBC3 IS THE ACTIVITY LEVEL OF BUYING HAY (UNITS ARE IN TONS)
* XBC4 IS THE ACTIVITY LEVEL OF BUYING ALFALFA (UNITS ARE IN TONS)
* XSL1 IS THE ACTIVITY LEVEL OF SELLING MILK (UNITS ARE IN CWT)
* XSL2 IS THE ACTIVITY LEVEL OF SELLING REPLACEMENT HEIFERS (UNITS ARE IN HEAD)
* XSL3 IS THE ACTIVITY LEVEL OF SELLING CULL COWS (UNITS ARE PER HEAD)
* XSL4 IS THE ACTIVITY LEVEL OF SELLING BULL CALVES (UNITS ARE PER HEAD)
* XSL5 IS THE ACTIVITY LEVEL OF SELLING HEIFER CALVES (UNITS ARE PER HEAD)
* XHB IS THE ACTIVITY LEVEL OF BUYING REPLACEMENT HEIFERS (UNITS ARE PER HEIFER)
* XHL1 IS THE ACTIVITY LEVEL OF BUYING LABOR (UNITS ARE IN HOURS)

```
*       XHL2 IS THE ACTIVITY LEVEL OF BUYING LABOR (UNITS ARE IN HOURS)
*       XHL3 IS THE ACTIVITY LEVEL OF BUYING LABOR (UNITS ARE IN HOURS)
*       XHL4 IS THE ACTIVITY LEVEL OF BUYING LABOR (UNITS ARE IN HOURS)
*       XHL5 IS THE ACTIVITY LEVEL OF BUYING LABOR (UNITS ARE IN HOURS)
*       XHL6 IS THE ACTIVITY LEVEL OF BUYING LABOR (UNITS ARE IN HOURS)
*       XFB IS THE ACTIVITY LEVEL OF BUYING NITROGEN FERTILIZER TO MEET CROP
        REQUIREMENTS
*       (O)(UNITS ARE IN LBS NITROGEN FERTILIZER)
*       XMS IS THE ACTIVITY LEVEL OF MANURE SYSTEM (UNITS ARE ONE SYSTEM)
*       RLT(r) IS THE LAND AVAILABLE FOR EACH LAND TYPE
*       RRLT1 IS THE LAND THAT CAN BE RENTED

Set

  I constraints transfer and resources

    /RLT1,RLT2,RLT3,RRL1,RRL2,RFL1*RFL6,RHL1*RHL6,RRCH,RRCH1,RCOT1
    RNTS1*RNTS6,RMT1*RMT6,RMKT,RHFT,RCOT,RCFT,RHYT,RHYNT1,RHYNT2,RAFT,
    RHYNT3,RAFNT1,RAFNT2,RCSLT,RRYT,RWHT,RPST,RCNT,RCOC,RHFC,RPNT,RPPT,
    RCCC,RPNT1,RPNT2,RPNT3,RCNNT,RCSLRNT,RCSLWNT,RCSLNT,RHYNT,RAFNT,
    RPRT,RNET,RPNET,RNO3,RWNT/

  J activities of the objective function

    / XLA1,XLA2,XCA1,XCA2,XCA3,XCA4,XCA5,XCA6,XCA7,XCA8,XSL5
    XCA9,XCA10,XCA11,XCA12,XRL1,XRL2,XSC1,XSC2,XSC3,XSL1,XSL2,
    XSL3,XSL4,XBC1,XBC2,XBC3,XBC4,XHB,XHL1,XHL2,XHL3,XHL4,XHL5,
    XHL6,FC2,FC3,FC4,FC5,FC6,FC7,FC8,XMS1,MD111,MD112,MD113,MD121,
    MD131,MD141,MD151,MD161,MD162,MD163,MD171,MD172,MD211,MD212,
    MD213,MD221,MD231,MD241,MD251,MD261,MD262,MD263,MD271,MD272,
    MD311,MD312,MD313,MD321,MD331,MD341,MD351,MD361,MD362,MD363,
    MD371,MD372,MD411,MD412,MD413,MD421,MD431,MD441,MD451,MD461,
    MD462,MD463,MD471,MD472,MD511,MD512,MD513,MD521,MD531,MD541,
    MD551,MD561,MD562,MD563,MD571,MD572,MD611,MD612,MD613,MD621,
    MD631,MD641,MD651,MD661,MD662,MD663,MD671,MD672,XFB1,XFB2,
    XFB3,XFB4,XFB5,XFB6,XFB7,XFB8,XFB9,XFB10,XFB11,XFB12/;


 PARAMETER A (I) RESOURCES CAPITAL LAND AND LABOR

/ RLT1   13
  RLT2   18
  RLT3   75
  RRL1   62
  RRL2   82
  RFL1   510
  RFL2   510
  RFL3   675
  RFL4   705
  RFL5   585
  RFL6   585 /;
```

TABLE AA (I,J)

	xla1	xla2	xca1	xca2	xca3	xca4	xca5	xca6	xca7	xca8	xca9	xca10
RLT1			1			1	1	1	1	1		
RLT2				1							1	
RLT3					1							1
RRL1												
RRL2												
RFL1	10.13	5.52										
RFL2	10.3	4.52				0.53			.53			
RFL3	9.68	2.48	0.9	0.9	0.9	1.44	3.21	3.21	1.44			
RFL4	9.77	1.52	1.13	1.13	1.13					2.92	2.92	2.92
RFL5	9.75	1.2				0.82	0.75	.75	.82	2.92	2.92	2.92
RFL6	10.37	1.28				0.2	0.29	0.29	0.2			

+	xca11	xca12	xrl1	xrl2	xsc1	xsc2	xsc3	xsl1	xsl2	xsl3	xsl4	xbc1	xbc2
RLT1	1		-1										
RLT2		1		-1									
RLT3													
RRL1			1										
RRL2				1									
RFL1													
RFL2													
RFL3	5.41	5.41											
RFL4	2.9	2.9											
RFL5	2.59	2.59											
RFL6													

+	xbc3	xbc4	xhb	xhl1	xhl2	xhl3	xhl4	xhl5	xhl6
RLT1									
RLT2									
RLT3									
RRL1									
RRL2									
RFL1				-1					
RFL2					-1				
RFL3						-1			
RFL4							-1		
RFL5								-1	
RFL6									-1

+	fc2	fc3	fc4	fc5	fc6	fc7	fc8	xms1	
RLT1									
RLT2									
RLT3									
RFL1								58	
RFL2								58	
RFL3								58	
RFL4								58	
RFL5								58	
RFL6								58	;

```
PARAMETER B(I) NITROGEN MANURE TRANSFER

 /RNTS1  0
  RNTS2  0
  RNTS3  0
  RNTS4  0
  RNTS5  0
  RNTS6  0
  RMT1   0
  RMT2   0
  RMT3   0
  RMT4   0
  RMT5   0
  RMT6   0 /;

 TABLE BB (I,J)
          xla1   xla2  xca1  xca2  xca3  xca4  xca5  xca6  xca7  xca8  xca9  xca10
    RNTS1
    RNTS2
    RNTS3
    RNTS4
    RNTS5
    RNTS6
    RMT1   -3450  -225
    RMT2   -3450  -225
    RMT3   -3450  -225
    RMT4   -3450  -225
    RMT5   -3450  -225
    RMT6   -3450  -225

    +     xca11  xca12  xsc1  xsc2  xsc3  xsl1  xsl2  xsl3  xsl4  xbc1  xbc2
    RNTS1
    RNTS2
    RNTS3
    RNTS4
    RNTS5
    RNTS6
    RMT1
    RMT2
    RMT3
    RMT4
    RMT5
    RMT6
```

+	xbc4	xhb	xhl1	fc2	fc3	fc4	fc5	fc6	fc7	fc8
RNTS1										
RNTS2										
RNTS3										
RNTS4										
RNTS5										
RNTS6										
RMT1										
RMT2										
RMT3										
RMT4										
RMT5										
RMT6										

+	xmsl	md111	md112	md113	md121	md131	md141	md151	md161	md162	md163	md171
RNTS1	696	-.79	-.79	-.79	-.79	-.79	-.79	-.79	-.79	-.79	-.79	
RNTS2	696											
RNTS3	696											
RNTS4	696											
RNTS5	696											
RNTS6	696											
RMT1	210375											
RMT2	210375											
RMT3	210375											
RMT4	210375											
RMT5	210375											
RMT6	210375											

+	md172	md211	md212	md213	md221	md231	md241	md251	md261	md262	md263	md271	md272	md311
RNTS1	-.79													
RNTS2		-.79	-.79	-.79	-.79		-.79	-.79	-.79	-.79	-.79	-.79		
RNTS3												-.79		
RNTS4														
RNTS5														
RNTS6														
RMT1														
RMT2														
RMT3														
RMT4														
RMT5														
RMT6														

+	md312	md313	md321	md331	md341	md351	md361	md362	md363	md371	md372
RNTS1											
RNTS2											
RNTS3	-.79	-.79									
RNTS4											
RNTS5											
RNTS6											
RMT1											
RMT2											
RMT3											
RMT4											
RMT5											
RMT6											

+	md411	md412	md413	md421	md431	md441	md451	md461	md462	md463	md471
RNTS1											
RNTS2											
RNTS3											
RNTS4	-.79	-.79	-.79								
RNTS5											
RNTS6											
RMT1											
RMT2											
RMT3											
RMT4											
RMT5											
RMT6											

+	md472	md511	md512	md513	md521	md531	md541	md551	md561	md562	md563
RNTS1											
RNTS2											
RNTS3											
RNTS4											
RNTS5		-.79	-.79	-.79			-.79	-.79	-.79		
RNTS6											
RMT1											
RMT2											
RMT3											
RMT4											
RMT5											
RMT6											

+	md571	md572	md611	md612	md613	md621	md631	md641	md651	md661	md662	md663	md671	md672
RNTS1														
RNTS2														
RNTS3														
RNTS4														
RNTS5														
RNTS6			-.79	-.79	-.79	-.79	-.79	-.79	-.79	-.79	-.79	-.79		
RMT1														
RMT2														
RMT3														
RMT4														
RMT5														
RMT6														

;

PARAMETER C(I) PRODUCTION CONSTRAINTS AND TRANFERS

```
/ RMKT   0
  RCOT   0
  RCFT   0
  RHFT   0
  RHYT   0
  RAFT   0
  RCSLT  0
  RRYT   0
  RWHT   0
  RPST   0
  RCNT   0
  RCCC   0
  RRCH   0 /;
```

TABLE CC (I,J)

	xla1	xla2	xca1	xca2	xca3	xca4	xca5	xca6	xca7	xca8	xca9	xca10
RMKT	-163											
RCOT												
RCFT	-.425											
RHFT	-.425	1										
RHYT									-3	-2.7	-2.5	
RAFT												
RCSLT						-18	-18	-18				
RRYT						-4						
RWHT							-5					
RPST			-2.4	-2.2	-2							
RCNT						-93						
RCCC	-.25											
RRCH	.25	-1										

+	xca11	xca12	xsc1	xsc2	xsc3	xsl1	xsl2	xsl3	xsl4	xsl5	xbc1	xbc2	xbc3
RMKT					1								
RCOT											-1		
RCFT								1					
RHFT									1				
RHYT				1								-1	
RAFT	-3	-3	1										
RCSLT													
RRYT													
RWHT													
RPST													
RCNT				1						-1			
RCCC							1						
RRCH						1							

+	xbc4	xhb	xhl1	fc2	fc3	fc4	fc5	fc6	fc7	fc8
RMKT										
RCOT										
RCFT										
RHFT										
RHYT				1						
RAFT	-1				1					
RCSLT						1				
RRYT							1			
RWHT								1		
RPST									1	
RCNT										1
RCCC										
RRCH		-1								

PARAMETER D(I) CROP NITROGEN REQUIREMENTS TRANFER

/ RPNT1 0
RPNT2 0
RPNT3 0
RCNNT 0
RCSLRNT 0
RCSLWNT 0
RCSLNT 0
RHYNT1 0
RHYNT2 0
RHYNT3 0
RAFNT1 0
RAFNT2 0 /;

TABLE DD (I,J)

	xla1	xla2	xca1	xca2	xca3	xca4	xca5	xca6	xca7	xca8	xca9	xca10	xca11	xca12
RPNT1			48											
RPNT2				48										
RPNT3					48									
RCNNT						113								
RCSLRNT							151							
RCSLWNT								170						
RCSLNT									113					
RHYNT1										49				
RHYNT2											49			
RHYNT3												49		
RAFNT1													0	
RAFNT2														0

+	xsc1	xsc2	xsc3	xsl1	xsl2	xsl3	xsl4	xbc1	xbc2	xbc3	xbc4	xhb	xhl1
RPNT													
RCNNT													
RCSLRNT													
RCSLWNT													
RCSLNT													
RHYNT													
RAFNT													

+	md111	md112	md113	md121	md131	md141	md151	md161	md162	md163	md171	md172
RPNT1	-1											
RPNT2		-1										
RPNT3			-1									
RCNNT				-1								
RCSLRNT					-1							
RCSLWNT						-1						
RCSLNT							-1					
RHYNT1								-1				
RHYNT2									-1			
RHYNT3										-1		
RAFNT1											-1	
RAFNT2												-1

+	md211	md212	md213	md221	md231	md241	md251	md261	md262	md263	md271	md272
RPNT1	-1											
RPNT2		-1										
RPNT3			-1									
RCNNT				-1								
RCSLRNT												
RCSLWNT												
RCSLNT							-1					
RHYNT1								-1				
RHYNT2									-1			
RHYNT3										-1		
RAFNT1											-1	
RAFNT2												-1

+	md311	md312	md313	md321	md331	md341	md351	md361	md362	md363	md371	md372
RPNT1	-1											
RPNT2		-1										
RPNT3			-1									
RCNNT												
RCSLRNT												
RCSLWNT												
RCSLNT												
RHYNT1												
RHYNT2												
RHYNT3												
RAFNT1												
RAFNT2												

+	md411	md412	md413	md421	md431	md441	md451	md461	md462	md463	md471	md472
RPNT1	-1											
RPNT2		-1										
RPNT3			-1									
RCNNT												
RCSLRNT												
RCSLWNT												
RCSLNT												
RHYNT1												
RHYNT2												
RHYNT3												
RAFNT1												
RAFNT2												

+	md511	md512	md513	md521	md531	md541	md551	md561	md562	md563	md571	md572
RPNT1	-1											
RPNT2		-1										
RPNT3			-1									
RCNNT												
RCSLRNT												
RCSLWNT												
RCSLNT												
RHYNT1								-1				
RHYNT2									-1			
RHYNT3										-1		
RAFNT												

+	md611	md612	md613	md621	md631	md641	md651	md661	md662	md663	md671	md672
RPNT1	-1											
RPNT2		-1										
RPNT3			-1									
RCNNT				-1								
RCSLRNT												
RCSLWNT												
RCSLNT							-1					
RHYNT1								-1				
RHYNT2									-1			
RHYNT3										-1		
RAFNT1											-1	
RAFNT2												-1

+	xfb1	xfb2	xfb3	xfb4	xfb5	xfb6	xfb7	xfb8	xfb9	xfb10	xfb11	xfb12
RPNT1	-1											
RPNT2		-1										
RPNT3			-1									
RCNNT				-1								
RCSLRNT					-1							
RCSLWNT						-1						
RCSLNT							-1					
RHYNT1								-1				
RHYNT2									-1			
RHYNT3										-1		
RAFNT1											-1	
RAFNT2												-1

```
PARAMETER E(I) LIVESTOCK FEED NUTREINTS TRANSFER

/ RPRT  0
  RNET  0
  RCOT1 150 /;


  TABLE EE (I,J)

          xla1  xla2  xca1  xca2  xca3  xca4  xca5  xca6  xca7  xca8  xca9  xca10 xca11 xca12
   RPRT   365   292
   RNET   8526  2905
   RCOT1

   +      xsc1  xsc2  xsc3  xsl1  xsl2  xsl3  xsl4  xbc1  xbc2  xbc3  xbc4  xhb   xhl1
   RPRT                                             -67.2
   RNET                                             -336
   RCOT1                                             1

   +      fc2     fc3     fc4     fc5     fc6     fc7     fc8
   RPRT   -83.82  -129.9  -25.4   -32     -28.06  -15.75  -2.05
   RNET   -981.9  -1009.3 -504.9  -299.7  -330.2  -75.11  -40.66
   RCOT1

                                                  ;


PARAMETER F(I) NITROGEN LOSS CONSTRAINT

/ RNO3 0 / ;


TABLE FF (I,J)

          md111 md112 md113 md121 md131 md141 md151 md161 md162 md163 md171 md172
   RNO3

   +      md211 md212 md213 md221 md231 md241 md251 md261 md262 md263 md271 md272
   RNO3

   +      md311 md312 md313 md321 md331 md341 md351 md361 md362 md363 md371 md372
   RNO3

   +      md411 md412 md413 md421 md431 md441 md451 md461 md462 md463 md471 md472
   RNO3

   +      md511 md512 md513 md521 md531 md541 md551 md561 md562 md563 md571 md572
   RNO3

   +      md611 md612 md613 md621 md631 md641 md651 md661 md662 md663 md671 md672
   RNO3
                                                         ;
```

```
PARAMETER G(I) COW NUMBER CONSTRAINT

/ RCOC  60
  RRCH1 15 /;

TABLE GG (I,J)

           xla1  xla2  xca1  xca2  xca3  xca4  xca5  xca6  xca7  xca8  xca9  xca10 xca11 xca12
     RCOC   1
     RRCH1        1                                                              ;


PARAMETER H(J) COST OF PRODUCTION LIVESTOCK AND CROPS

/ xla1      -827
  xla2      -643
  xca1       -33
  xca2       -33
  xca3       -33
  xca4       -97
  xca5      -213
  xca6      -213
  xca7      -126
  xca8       -62
  xca9       -62
  xca10      -62
  xca11     -162
  xca12     -162 /;

PARAMETER K(J) PRICES RECIEVED FOR LIVESTOCK AND CROP PRODUCTS

/xsc1      99.99
 xsc2      49.99
 xsc3       3.00
 xsl1        13
 xsl2       983
 xsl3       625
 xsl4        85
 xsl5        85 /;
```

```
PARAMETER L(J) PRICES PAID FOR PRODUCTION UNIT HEIFERS LABOR AND FERTILIZER

/ xbc1      -3.01
  xbc2      -160
  xbc3      -50
  xbc4      -100
  xhb       -984
  xhl1      -5
  xhl2      -5
  xhl3      -5
  xhl4      -5
  xhl5      -5
  xhl6      -5
  xfb1      -.26
  xfb2      -.26
  xfb3      -.26
  xfb4      -.26
  xfb5      -.26
  xfb6      -.26
  xfb7      -.26
  xfb8      -.26
  xfb9      -.26
  xfb10     -.26
  xfb11     -.26
  xfb12     -.26
  xms1      -2980
  xrl1      -50
  xrl2      -35/;


VARIABLES

Z      net revenue value of objective function
X(J)   activities                             ;

Positive VARIABLES X ;

EQUATIONS

NR             net revenue objective function
RES(I)         land capital family labor hired labor constraint
PRODUCT(I)         production tranfer
MANTRAN(I)          manure tranfer from system to crop
CRNUTTRN(I)         crop nitrogen requirements tranfer
LIVEFEED(I)        livestock activity from crop activity
COWCON(I)           cow number constraint;

 NR..  Z=E=sum(j, x(j)*h(j))+sum(j, x(j)*k(J))+sum(j, x(j)*l(j));
 RES(I)..      sum(j, x(j)*aa(i,j))=L= a(i);
 MANTRAN(I)..  sum(j, x(j)*bb(i,j))=E= b(i);
 PRODUCT(I)..  sum(j, x(j)*cc(i,j))=L= c(i);
 CRNUTTRN(I).. sum(j, x(j)*dd(i,j))=E= d(i);
 LIVEFEED(I).. sum(j, x(j)*ee(i,j))=L= e(i);
 COWCON(I)..   sum(j, x(j)*gg(i,j))=E= g(i);

  Model DFar60  /all/;

 Solve DFar60 using LP maximizing Z ;

 Display x.l, x.m;
```

VITA

Stephen Gary Bullen was born in Berea, Kentucky, July 8, 1956. He attended and graduated from Rockcastle County High School in May, 1974. He attended Eastern Kentucky University from 1974 to 1978, receiving a Bachelor of Science Degree in Agricultural Business. From 1978 until 1981, he served as a volunteer in Israel, working with orange grove production. Upon returning to the United States, he accepted a position as a County Extension Agent with the University of Tennessee in Greene County, Tennessee. After working as a county agent for six years, he began work towards a Master of Science degree at the University of Tennessee in January, 1987. In December of 1990, he completed a Master of Science degree in Extension Education. In addition to the Masters of Science in Extension Education he completed a Master of Science in Agricultural Economics. His studies focused on Development and Natural Resources.

He is a member of Gamma Sigma Delta Agricultural Honor Society. He is married to Carolyn Janelle Hooper from Greer, South Carolina. They have two children, Nathan and Elisha Beth.