THE USE OF EPIC TO EVALUATE NUTRIENT LOADS FROM CROP LAND IN THE CHESAPEAKE BAY BASIN

Final Report

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Executive Summary

Excess nutrients are believed to be responsible for the deterioration of water quality in Chesapeake Bay, and nutrient management is an essential element in the efforts to reduce nutrient loads entering the Bay. Nutrient management is believed to be the most cost-efficient method of reducing nutrients from agricultural sources. It is difficult, however, to quantitatively determine the effectiveness of nutrient management in reducing the off-field transport of nitrogen and phosphorus. Empirical studies entail the long-term monitoring of runoff, erosion, and percolation, which is prohibitively expensive. Computer simulation, on the other hand, can supplement empirical investigation by simulating the long-term environmental impacts of agricultural practices under a variety of conditions. It can provide an internally-consistent framework for evaluating the effect of variability in soils, weather, and topography on the efficiency of nutrient management in reducing nutrient losses across the Chesapeake Bay Basin.

This project attempts to quantify the effectiveness of nutrient management through the computer simulation of representative farming operations across the Chesapeake Bay Basin. The computer model EPIC (Environmental Policy Integrated Climate) was used to perform the simulations. EPIC is a field-scale model, operating on a daily time-step, which can simulate hydrology, erosion, nutrient cycling, crop growth and changes in the soil profile. It does not require calibration. It represents hydrological, chemical, and biological processes through standard, verified parametric relationships such as the Curve Number Procedure or the Universal Soil Loss Equation. The input data necessary to run EPIC--data on soils, crops, farming operations, and daily weather data--are also readily available.

Simulation were performed for typical crop rotations on the following seven types of agricultural operations:

1-Dairy and Poultry Operation in Limestone Valley Region, Virginia
2-Poultry Operation in Limestone Valley Region, Virginia
3-Dairy and Swine Operation in Ridge and Valley Region, Pennsylvania
4-Dairy Operation in Piedmont Region, Pennsylvania
5-Poultry Operation in the Coastal Plain, Maryland
6-Cash Grain Operation in the Coastal Plain, Maryland
7-Poultry and Cash Grain Operation in the Coastal Plain, Maryland

Except for the second Maryland farm, the Cash Grain Operation in the Coastal Plain, which used only inorganic fertilizer, all of the farms used animal manures, and nutrient management was, to a large extent, directed at determining the optimal rate, timing, and method of application of the manures.

For each farm operation, typical crop rotations were simulated, both before and after nutrient management. Environmental nutrient losses before and after nutrient management were

compared. For the purposes of this project, environmental losses were defined to be losses of nitrogen and phosphorus in erosion, runoff, and subsurface flow outside the boundaries of the represented soil profile. These are edge-of-field losses, and do not represent the losses delivered to surface water or ground water.

The efficiency of nutrient management was quantified by comparing the simulated nutrient losses from a scenario before nutrient management to the losses in the scenario after nutrient management. The efficiency of nutrient management is the percent reduction in nutrient losses as calculated by the computer simulation

$$\text{Nutrient Reduction Efficiency} = \frac{\text{losses in simulation without nutrient management} - \text{losses in simulation with nutrient management}}{\text{losses in simulation without nutrient management}}$$

The sensitivity of both nutrient reduction efficiency and nutrient losses to manure mineralization rate, denitrification rate, slope, and soil type was examined.

The results of the simulations demonstrated that nutrient management is very effective in reducing nutrient losses. Simulated nitrogen reduction efficiencies ranged from 24% to 75%. For those scenarios in which phosphorus inputs were reduced by nutrient management, simulated phosphorus reduction efficiencies ranged from 29% to 52%.

Nutrient management does not eliminate nutrient losses. After nutrient management, simulated average annual phosphorus losses ranged from 2.2 lb/ac to 10.7 lb/ac annually. Except for a silage corn rotation in the Piedmont Region of Pennsylvania, total annual average phosphorus losses were 10% or less of the average annual phosphorus applied in fertilizer or manure. After nutrient management, simulated total average annual nitrogen losses ranged from 29.0 lb/ac to 88.3 lb/ac. The percentage of nitrogen lost, as a fraction of nitrogen applied in fertilizer and manure, was always greater than 10%, and ranged as high as 46%.

In EPIC, all organic nitrogen is represented as mineralizing at the same rate as humus in the soil. Since the soil mineralization rate is much slower than the reported rates for manures, half of the organic nitrogen in manure which becomes available in the first year after application was applied as nitrate. A sensitivity analysis was performed for each simulation to determine the effects on nitrogen losses and nitrogen reduction efficiency of the manure mineralization rate. Simulated nitrogen losses increased when the fraction of organic nitrogen in manure available in the first year was increased, but nitrogen reduction efficiencies were not significantly affected by the representation the of the amount of organic nitrogen available in the first year after mineralization.

Nitrogen reduction efficiency was also insensitive to denitrification rates. The simulations were run with minimal denitrification. The effects of denitrification were analyzed by assuming that 10%, 20%, or 50% of subsurface nitrogen losses were the result of denitrification. The impact on nitrogen reduction efficiencies were minimal.

The simulations in Virginia and Pennsylvania were performed on different soils to examine the effect of soil type on losses and nutrient reduction efficiency. On the limited range of soils examined, soil type did not have a large impact on nutrient reduction efficiency, although the amount of losses could vary if the amount of runoff, subsurface flow, or erosion varied with changes in soil properties. All simulations were also run on a range of slopes. Increasing the slope increased nutrient losses and tended to decrease nitrogen reduction efficiencies. Nitrogen reduction efficiency decreased as much as 16% over the range of slopes simulated. Although phosphorus losses increased due to increases in erosion, the effect on phosphorus reduction efficiency was minimal.

There was more variation in nutrient reduction efficiency between different crop rotations than among the simulations using the same crop rotation but using different soils or slopes. Crop rotation has a large role in determining the effectiveness of nutrient management, and nutrient reduction efficiency cannot be predicted on the basis of the reduction of nutrient inputs and crop needs alone.

These simulations confirm that nutrient management is a cost-effective means for reducing nutrients from agriculture and helping the Chesapeake Bay Program meet its goal of reducing nutrient loads to the Bay by 40%. Most of the scenarios simulated reduced edge-of-field nitrogen losses by more than 40%. Nitrogen reduction efficiency was higher in those scenarios where losses were higher, suggesting that nutrient management can be most beneficial in those situations where it is most needed. While the phosphorus reduction efficiency of nutrient management was greater than 40% in fewer scenarios, in all but one of the scenarios where phosphorus inputs were reduced, simulated phosphorus losses after nutrient management were 10% or less of phosphorus inputs, indicating that by another measure of efficiency, nutrient management led to the efficient use of phosphorus.

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Chapter One

Introduction

Nutrient management is the attempt to determine the optimal rate, timing, and method of the application of nutrients to crop land in order to supply crops with sufficient nutrients to meet targeted yields yet minimize the transport of nutrients from crop land to surface and ground water. Excess nitrogen and phosphorus from manure and inorganic fertilizers can be transported in erosion, runoff, and percolation. When these nutrients enter surface water, they can cause environmental problems. Excess nutrients can lead to algal blooms that limit the light available for other forms of aquatic vegetation. The death and decay of the algal population may ultimately deplete the oxygen supply for other forms of aquatic life.

Excess nutrients are believed to be responsible for the deterioration of water quality in Chesapeake Bay, and nutrient management is an essential element in the efforts to reduce nutrient loads entering the Bay. Nutrient management is believed to be the most cost-efficient method of reducing nutrients from agricultural sources. The cost of developing nutrient management plans are small, compared to structural best management practices (BMPs). If a farmer has been applying excess amounts of inorganic fertilizer, the implementation of a nutrient management plan can reduce fertilizer costs. Nutrient management can promote more efficient use of animal manures for fertilizer.

It is difficult, however, to quantitatively determine the effectiveness of nutrient management in reducing the off-field transport of nitrogen and phosphorus. Empirical studies entail the long-term monitoring of runoff, erosion, and percolation, which is prohibitively expensive. Computer simulation, on the other hand, can supplement empirical investigation by simulating the long-term environmental impacts of agricultural practices under a variety of conditions. It can provide an internally-consistent framework for evaluating the effect of variability in soils, weather, and topography on the efficiency of nutrient management in reducing nutrient losses across the Chesapeake Bay Basin.

This project will attempt to quantify the effectiveness of nutrient management through the computer simulation of representative farming operations across the Chesapeake Bay Basin. The computer model EPIC (Environmental Policy Integrated Climate, formerly Erosion Productivity Calculator) will be used to perform the simulations. EPIC was developed by the Agricultural Research Service (ARS) of the United States Department of Agriculture. It is a field-scale model, operating on a daily time-step, which can simulate hydrology, erosion, nutrient cycling, crop growth and changes in the soil profile. EPIC does not require calibration. It represents hydrological, chemical, and biological processes through standard, verified parametric relationships such as the Curve Number Procedure or the Universal Soil Loss Equation. The input data necessary to run EPIC--data on soils, crops, farming operations, and daily weather data--are also readily available. In short, EPIC is a detailed and sophisticated model, relatively easy to use, that has already been successfully applied in computer simulations of agronomic practices across the country. More details of the use of EPIC in this project are discussed in Chapter Two.

Representative Crop Scenarios

The Research Evaluation and Management (REM) Workgroup of the Nutrient Subcommittee of the Chesapeake Bay Program specified the farming scenarios for this project. Although the possibility was originally left open of examining the effectiveness of other non-structural BMPs, such as cover crops or conservation tillage, all scenarios suggested by the REM workgroup concerned the effectiveness of nutrient management. Most of the scenarios also incorporate cover crops or some form of conservation tillage in their rotations.

The representatives to the REM Workgroup of Virginia, Pennsylvania, and Maryland suggested two scenarios each. The two Maryland scenarios were more easily treated as three distinct scenarios, however, leading to the following list of seven scenarios:

1-Dairy and Poultry Operation in Limestone Valley Region, Virginia
2-Poultry Operation in Limestone Valley Region, Virginia

3-Dairy and Swine Operation in Ridge and Valley Region, Pennsylvania
4-Dairy Operation in Piedmont Region, Pennsylvania
5-Poultry Operation in Coastal Plain, Maryland
6-Cash Grain Operation in Coastal Plain, Maryland
7-Poultry and Cash Grain Operation in Coastal Plain, Maryland

Each scenario is broadly specified by a schedule of farming operations, both before and after nutrient management. Almost all of the scenarios use animal manures, and nutrient management is, to a large extent, directed at directed at determining the optimal rate, timing, and method of application of the manures. The second Maryland scenario, the Cash Grain Operation in the Coastal Plain, uses only inorganic fertilizer, and in this case the distinction between before and after nutrient management does not apply.

The members of the REM Workgroup directed other state officials to determine the details of the farm schedules. These officials supplied the following information for farm schedules both before and after nutrient management:

- The planting and harvesting dates of the crops in the rotation.
- Dates of tillage operations.
- Timing, rate, and method of application of inorganic fertilizer applications.
- Timing, rate and method of application of manure and litter applications.
- The nutrient content of the manure or litter.

In addition, the targeted or anticipated crop yield for each crop in the rotation was often supplied. Sources for the other input data for the EPIC model are discussed in Chapter Two. The details of the schedules of farm operations are discussed in the chapters for each scenario.

The Simulation of Environmental Nutrient Losses and Nutrient Reduction Efficiency

EPIC represents most of the major components of the nitrogen and phosphorus cycles in agricultural soils. It keeps a strict balance on the nitrogen and phosphorus in the soil, in the standing crop, and in the crop residue. All inputs and all off-field losses are strictly account for.

Not all components of nutrient cycle are available as simulation output, however, so it is not possible to strictly calculate the nitrogen or phosphorus balance on a daily, monthly, or annual basis. Nonetheless, in the case of nitrogen at least, the concept of a nitrogen budget will prove useful in accounting for the fate of nitrogen applied to the crops. Fewer transformations of phosphorus are represented in EPIC and the concept of a budget is less useful. In general, more attention will be paid to nitrogen in this report, in part because the complexities of the nitrogen cycle require more analysis, in part because of the emphasis placed on controlling nitrogen as the limiting nutrient in the estuaries of Chesapeake Bay.

For the purposes of this project, environmental losses are defined to be losses of nitrogen and phosphorus in erosion, runoff, and subsurface flow outside the boundaries of the represented soil profile, which in almost all cases is deeper than the root zone. These are edge-of-field losses. They do not represent the losses delivered to surface water or ground water. They do not take into account the transport of eroded soil from the field to surface water or the transformations nutrients may undergo from ground water to surface water. All losses, as well as all components of the nutrient cycles, are reported in units of elemental nitrogen or phosphorus.

The efficiency of nutrient management can be quantified by comparing the simulated nutrient losses from a scenario before nutrient management to the losses in the scenario after nutrient management. The efficiency of nutrient management is the percent reduction in nutrient losses as calculated by the computer simulation

$$\text{Nutrient Reduction Efficiency} = \frac{\text{losses in simulation without nutrient management} - \text{losses in simulation with nutrient management}}{\text{losses in simulation without nutrient management}}$$

Although nutrient reduction efficiency will be treated as the primary measure of the effectiveness of nutrient management, nutrient losses, both before and after nutrient management, will be reported, and the sensitivity of both nutrient reduction efficiency and nutrient losses to slope, mineralization rate, and soil type will be examined.

Chapter Two

An Outline of EPIC's Model Structure and Its Representation of Manure Applications

EPIC is one of the most sophisticated computer models, capable of simulating the losses of nitrogen and phosphorus in runoff, percolation, and erosion from crop land. Many processes in the hydrologic, nitrogen, and phosphorus cycles are represented in EPIC. Frequently, widely-used methods, such as the Curve Number Procedure for estimating runoff or the Universal Soil Loss Equation (USLE) for estimating erosion, have been incorporated into EPIC. Other processes are represented by models developed especially for use in EPIC.

Even when widely-used methods have been incorporated into EPIC, they are sometimes modified to meet the objectives of the model. USLE is a method for estimating annual erosion from a field. In EPIC, it is adapted to estimate erosion from individual storms. Similarly, the Curve Number Procedure has been modified to estimate the runoff from any amount of daily precipitation, and not just the 10-year storm or design storm for a culvert or drainage ditch. Modifications are often made to take advantage of the fact that in a simulation, information is available that cannot be routinely determined in the field. For example, curve numbers can be calculated on a daily basis so they reflect the moisture content and the infiltration capacity of the soil, or USLE can calculate daily erosion based upon the simulated crop cover as measured by the biomass of the standing crop. In this respect, EPIC adds a degree of both sophistication and complexity to the models it uses by integrating the results of one model into the input of another.

No model can capture all the complexity of real systems. It is important to identify to what extent a model's representation of phenomena may not be adequate to the phenomena themselves. Some account must be given of a model's limitations, in order to correctly interpret its results. In the case of EPIC, although it has the capacity to apply manure and other organic fertilizers to crops, its representation of the role of manure in the nutrient cycle may be open to question. Since the role of manure is central to these simulations, it is essential review the limitations EPIC has in representing manure and the steps that might be taken to compensate for those limitations.

In order to provide a context for interpreting and evaluating the results of these simulations, a qualitative overview of EPIC's representation of the hydrologic and nutrient cycles will be given in this section. The review will be brief and selective, concentrating on features necessary for understanding modeling results or features which might put those results into question. The overview will emphasize EPIC's representation of the role of manure in the nutrient cycle, but it will touch on EPIC's representation of other process and the modifications made to familiar methods like the Curve Number Procedure and USLE. More details can be found in the model documentation, "The EPIC Model" (Williams, 1994).

The review will also discuss the input data necessary for the model and the sources of the data used in these simulations. It goes without saying that good modeling results often depend on having good input data. One of the advantages of EPIC is that much of the input data it requires is readily available. Nevertheless, it is important to identify the input data used in the model and their sources.

Hydrologic Cycle

Weather data. EPIC requires daily values for precipitation, maximum temperature, minimum temperature, solar radiation, average wind speed and average relative humidity. Daily values for some or all of these parameters can be read from an input file, or EPIC can generate its synthetic weather data, based on summary statistics calculated for weather stations around the country. These summary statistics are supplied with the EPIC software. In these simulations, actual weather records were used for precipitation, maximum temperature, and minimum temperature; the other required values were generated by EPIC. Weather records were obtained from the National Climatic Data Center's Summary of the Day database. Of the daily meteorological values generated by EPIC, only solar radiation is used. The only statistic used to generate it is monthly mean solar radiation. Another meteorological statistic, the monthly average half-hour rainfall intensity, is used in calculating erosion.

Runoff. As mentioned earlier, the Curve Number Procedure is used to calculate daily runoff.

Curve numbers are adjusted daily to take into account soil moisture in the root zone. EPIC also adjusts the curve number to take into account the slope of the field. If the slope is greater than 5%, the curve number is increased, and if the slope is less than 5%, the curve number is decreased. Fields with slopes of 5% are uncorrected.

Potential evapotranspiration. Four different equations can be used in EPIC to calculate evapotranspiration. Of the four, Hargreaves Equation best fit the available annual lake evapotranspiration data, so it was used in these simulations. It has the additional advantage that it depends only on daily maximum and minimum temperature and daily maximum potential solar radiation, so it is independent of any assumptions used in the generation of synthetic weather data.

Lateral subsurface flow and percolation. If water is not removed from the soil by evapotranspiration, it is subject to percolation and lateral subsurface flow. In this context, percolation refers to the flow through successive soil layers. When percolation is reported in simulation results, it refers to the quantity of water flowing out of the soil profile and hence out of the model boundary. Lateral subsurface flow refers to the lateral flow of water within a soil layer. When water flow laterally, by that fact it passes outside the boundaries of the model simulation. This quantity of water is reported as lateral flow.

Whenever the water content of a soil layer is above field capacity, water will flow out of that layer in lateral flow and percolation at a rate determined by the porosity and saturated conductivity of the layer. Travel time in lateral flow is also inversely proportional to the slope of the field: the larger the slope, the smaller the travel time, and the greater the rate at which water will leave a layer by lateral flow. The quantity of water leaving a layer by percolation and lateral flow is determined simultaneously, but, because of the dependence of travel time in lateral flow on slope, more water will flow in percolation.

Soil Properties and Erosion

Soil data. EPIC requires a wide range of soil properties for each soil layer represented in the model. Many of these soil properties, such as the percentage of sand, silt, clay, and organic matter in a soil layer, or the porosity or saturated conductivity, are available in the Natural Resource Conservation Service's SOILS-5 database. The ARS has made available a software tool, MUUF (Mapping Unit Use File) , which not only provides soil properties from the SOILS-5 database, but puts them in a form that can be directly loaded into EPIC input files.

Some soil properties, like the initial concentration of nitrogen and phosphorus in the soil, are estimated by EPIC if they are not known. In these simulations, the initial concentrations of nitrogen and phosphorus were estimated by EPIC.

No matter how many soil layers are defined in the soil profile, EPIC divides the soil profile into ten layers. The top layer's thickness is fixed at one centimeter. This top layer defines the zone of interaction between the soil and runoff. The concentrations of nutrients in erosion and runoff are calculated on the basis of the properties of the top soil layer.

In the course of a simulation soil properties can change in three ways: (1) nutrient cycling can change the concentrations of nutrients, organic matter, and plant residue in a soil layer, (2) tillage operations can mix the constituents of two or more soil layers, and (3) as soil is eroded, soil layers can be redefined to try to preserve the ten layer distribution of layers in the soil profile and the one centimeter depth of the top layer of soil.

Erosion. On an annual or monthly basis, USLE determines erosion as a product of an rainfall energy factor, a crop management factor, a slope factor, a soil erodibility factor, and a conservation practice factor. In EPIC, soil erodibility is calculated annually on the basis of the sand silt, clay, and organic matter fractions of the top soil layer, which is fixed at a thickness of one centimeter. The rainfall energy factor and the crop management factor are calculated on a daily basis, based on inputs and state variables in the simulation. The crop management factor is a function of the aboveground biomass and residue. The more biomass in the crop and the more residue on the ground, the more erosion is suppressed. The rainfall energy factor is dependent on the monthly average half-hour rainfall intensity and daily rainfall.

EPIC also has a correction factor that takes into account the percentage of coarse rock fragments in the soil. The greater the percentage of coarse fragments, the less erosion takes place.

Nutrient Cycling

EPIC has a representation of four species of nitrogen: ammonia/ammonium nitrogen, nitrate, active organic nitrogen, and stable organic nitrogen. Four species of phosphorus are represented: organic phosphorus, labile mineral phosphorus, active mineral phosphorus, and stable mineral phosphorus. In addition, EPIC keeps track of the nitrogen and phosphorus in crop biomass and in fresh organic matter, representing both crop residue and soil microbial biomass.

The various species of nitrogen are transformed by the familiar pathways of the nitrogen cycle. Ammonia nitrogen can be volatilized, taken up by the crop, or converted to nitrate through nitrification. Nitrate can be taken up by the crop, denitrified, or immobilized. Immobilized nitrogen is added to the pool of nitrogen in fresh organic matter. The nitrogen in fresh organic matter can be broken down into nitrate and soil organic nitrogen, which represents the nitrogen content of humus. Active organic nitrogen can be mineralized into nitrate. Stable organic nitrogen differs from active organic nitrogen in that it cannot be mineralized directly, but an equilibrium is maintained between the active and stable pools of organic nitrogen, so that the relative size of the pools remain proportional in a ratio determined by the number of years the simulated field has been under cultivation.

The phosphorus species can also be transformed into one another. Labile phosphorus represents phosphorus that is readily available to the crop. It can be operationally defined as the phosphorus determined using the anion exchange resin method, and represents both the phosphate in the soil solution and the phosphate sorbed to the soil in equilibrium with the soil solution. Active mineral phosphorus and stable mineral phosphorus represent different degrees of availability of mineral phosphorus to the crop. While only labile phosphorus can be taken up by the crop, the active mineral phosphorus pool is in equilibrium with the labile pool. The ratio between the pools is a function of the calcium carbonate concentration in the soil, the pH, base saturation, and other soil properties. The active and stabile mineral pools are also in equilibrium, and their relationship is analogous to that between the active and stable organic nitrogen pools. Organic phosphorus can be mineralized to labile phosphorus. The phosphorus in the pool of fresh organic matter can be mineralized to labile phosphorus and organic phosphorus. Labile phosphorus can also be immobilized and added to the pool of phosphorus in fresh organic matter.

Although EPIC maintains a strict mass balance on all components of the nitrogen and phosphorus cycles, output data is not available on all components of the cycles. In particular, it is difficult to know, at a given point in time, how much nitrogen and phosphorus is in the standing crop, how much has been harvested, and how much is in residue. Although the nitrogen content of a harvest is an output variable, the phosphorus content is not, though it can be inferred from the nitrogen content of the crop yield: the phosphorus content of crop yield is approximately one-seventh of the nitrogen content of the yield.

Environmental losses of nutrients. Environmental nutrient losses are those nutrient losses transported in runoff, erosion, percolation, and lateral flow. Not all species of nutrients can be transported in all phases. For nitrogen, only nitrate can be transported in runoff, percolation, and lateral flow, and only active and stable organic nitrogen is lost in erosion. For phosphorus, while all species of phosphorus are transported in erosion, only labile phosphorus is transported in runoff and percolation. No phosphorus is transported in lateral flow.

Again, the details of these loss mechanisms can be found in Williams, 1994. In general, EPIC's representation of nutrient losses should not be controversial. Nitrate losses are proportional to the flows in runoff, lateral flow, and percolation from a layer. Nitrogen leaves a layer in the same concentration in all three paths. Labile phosphorus losses in runoff are proportional to the concentration of labile phosphorus in the top soil layer. Nitrogen and phosphorus erosion losses are proportional to the concentrations of organic nitrogen and phosphorus, respectively, in the top soil layer, the quantity of erosion, and an enrichment factor to account for the fact that more fine grain sediment, with higher concentrations of nutrients, is disproportionately lost in erosion.

The loss of labile phosphorus in percolation calls for some comment. In EPIC, the ratio of labile phosphorus transported in percolation to phosphorus remaining in the soil layer is proportional to the weight of the percolated water to the weight of the soil layer. Since the latter ratio tends to be small, the former tends also to be small, and phosphorus losses in percolation are often negligible. It is important to note that EPIC does not explicitly model phosphorus sorption and does not therefore set an upper limit on the phosphorus sorption capacity of the soil. Thus EPIC does not represent the breakthrough behavior hypothesized to occur when the phosphorus sorption capacity of the soil is exhausted and phosphate is more easily transported into groundwater and perhaps surface water. Moreover, it is not even possible to identify scenarios likely to exhibit breakthrough behavior on the basis of simulated soil phosphorus concentrations, because there is no method to quantify the phosphorus sorption capacity of a soil on the basis of soil properties.

In general, the analysis of phosphorus losses will receive less attention than the analysis of nitrogen losses. As previously mentioned, not all the major components of the phosphorus cycle are readily available as output in EPIC. Phosphorus losses are primarily a function of erosion and the buildup of soil phosphorus concentrations. Since phosphorus is relatively immobile in the soil, losses are not as dependent on the hydrologic cycle and the timing of farming operations.

Denitrification

The extent of denitrification is a subject of much controversy. Some believe that denitrification is minimal in well-drained soils; other believe that denitrification can lead to substantial losses of soil nitrate even in soils that are not poorly-drained. Meisinger and Randall (1991) surveyed recent studies of denitrification and summarized their findings. They suggest that on well-drained soils, 4-16% of inorganic nitrogen fertilizer would be lost through denitrification, and double that amount of nitrogen would be lost from manure. Losses from soils under no-tillage would be higher still, 6-20% of applied inorganic nitrogen with losses doubled from manure. Although

Meisinger and Randall state that their estimates of denitrification are not as high as some estimates, their estimates are higher than the estimates of those who feel that denitrification is minimal on well-drained soils.

EPIC currently represents denitrification as a first-order process. Denitrification losses are proportional to the quantity of nitrate in the soil layer, corrected for temperature and the content of organic matter in the soil, if the soil moisture content is above a certain threshold. Both the moisture content threshold and the denitrification rate constant can be set, although the highest threshold value possible is field capacity.

An attempt was made to calibrate the threshold parameter and the rate parameter so that denitrification losses fell within the range suggested by Meisinger and Randall. No pair of parameters worked for all scenarios, however, so the attempt to represent denitrification within the scenarios was abandoned. The denitrification rate was set to a minimum, and the potential impact of denitrification will be analyzed at the conclusion of this study, where a range of potential denitrification rates will be examined.

Crop Yields and the Nitrogen Content of Crop Yield

EPIC reports both the crop yield and the nitrogen content of crop yield. The nitrogen content of crop yield represents only the nitrogen taken off the field in the harvest. It does not include the nitrogen in residue or biomass of the plants after harvest.

The crop yields are reported in EPIC in dry weight. Meisinger and Randall (1991) compiled data relating the nitrogen content of the crop yield with yields reported at standard grain water content. If this data is used to calculate simulated yields on the basis of the nitrogen content of the yield, there is general agreement between simulated yields and anticipated crop yields at standard grain water content. This procedure will be used to report simulated yields in this study. Table 2.1 summarizes the relevant data from Meisinger and Randall for the crops simulated in these scenarios.

The Representation of Manure Applications in EPIC

EPIC has the capability of representing both organic and inorganic fertilizers. The composition of fertilizers can be represented as any combination of three species of nitrogen: ammonia nitrogen, active organic nitrogen, or nitrate. Fertilizer can also be applied as either organic phosphorus or labile phosphorus. It would seem natural, then, to represent manure as a combination of ammonia nitrogen, organic nitrogen, and organic phosphorus. There are consequences, however, to representing manure as organic nitrogen, both for water quality and for the nutrient needs of the crop.

In EPIC, organic nitrogen is not mobile. The only way it can change soil layers is by tillage. Yet research suggests that at least a fraction of organic nitrogen is soluble, and can be transported in both runoff and percolation. Steenhuis et al. (1981) identified a portion of soluble organic nitrogen in dairy manure that was distinct, not only from ammonium nitrogen but also from urea. This soluble organic nitrogen was a constituent of both runoff from snow melt and the infiltration of the melted snow pack when dairy manure was applied on fields in the winter. In Edwards and Daniel's study of runoff from fescue plots on which swine manure (1993) and poultry manure (1994) had been applied, not all of the total Kjeldahl nitrogen lost in runoff was in ammonium form.

A more serious problem is when the organic nitrogen in manure becomes available to the crops. In order for the crop to take up nitrogen, it must be in the form of nitrate or ammonia. The organic nitrogen in manure must first mineralize, before it becomes available to the crops. In EPIC, all organic nitrogen mineralizes at the rate of humus, which is rather slow compared to the mineralization rates typical of manures. The humus mineralization rate in EPIC is 0.0003 d^{-1}. Reddy et al. (1979), in their literature survey of manure mineralization rates, found the mineralization rates reported for poultry manure to be about two orders of magnitude higher, and beef and pig manures to be one to two orders of magnitude higher, than EPIC's soil mineralization rate. If manure is represented as organic nitrogen in EPIC, most of it will not be available to the crop in the year that it is applied. It will also not be as vulnerable to transport in runoff and percolation as it would be if it were transformed into nitrate at the rates reported in the literature.

To address these problems, it was decided to represent manure in EPIC as a mixture of ammonia, organic nitrogen, and nitrate. At the suggestion of Mr. Russ Perkinson of Virginia's Department of Conservation and Recreation, one-half of the organic nitrogen that is available to the crop in the first year after application was represented as nitrate. The fraction of manure applied as nitrate differs according to the animal involved and the state, for the states in the Chesapeake Bay Basin do not all agree on how much of the organic nitrogen in the applied manure is available to the crops in the crop in the first year. Table 2.2 shows the nutrient content of the manures and litters used in this study, and the fraction of organic nitrogen assumed to be mineralized in the first year after application. All phosphorus in manure was applied as labile phosphorus.

To repeat, part of the nitrogen available to the crop in the first year is applied as nitrate for two reasons: (1) to more realistically represent the potential for environmental losses of nitrogen in runoff and percolation, and (2) to supply the crops with available nitrogen in a more timely manner. A sensitivity analysis was performed for each simulation to test how the choice of the fraction of organic nitrogen applied as nitrate affected nutrient losses and the nitrogen reduction efficiency of nutrient management.

While the solubility of organic nitrogen in manure is captured by applying some of the available organic nitrogen in manure as nitrate, the erodibility of manure and its impact on the erodibility of the soil has not been table into account. Khaleel et al. (1981) noted that studies have shown that manure applications tend to increase the infiltration capacity of the soil and reduce erosion and runoff. EPIC partially takes this into account by the way in which increases in soil organic matter decrease the erodibility of the soil. When manure is surface-applied, however, manure particles are in effect the soil surface, and have different properties than the soil itself. Westerman et al.

(1983) tried to estimate the erodibility of manure, and concluded it could differ significantly from that of the underlying soil. They reported that other factors, like the time that elapsed between the manure application and the runoff event, could affect the quantity and composition of runoff and erosion from manured fields. It is likely, therefore, that EPIC does not fully represent the transport mechanisms that affect surface-applied manure, although since most of the nitrogen lost in runoff is in soluble form, the impact of eroded manure may be secondary. In the absence of a computer model which incorporates all of the complex interactions between soil and manure, EPIC is at least responsive to those factors, like rainfall intensity and the concentration of nitrogen and phosphorus in the top layer of soil, which are most likely to affect nutrient losses in runoff and erosion.

Chapter Three

First Virginia Scenario: Poultry and Dairy Operation in the Limestone Region

Scenario Description

The first Virginia scenario represents continuous corn silage/rye silage double crop on a poultry and dairy operation in the limestone region in the Shenandoah Valley. The soil is a Frederick silt loam with a 7-15% slope. The slope was set at 10% for these simulations. Table 3.1 gives the schedule of farming operations for the rotation before nutrient management, and Table 3.6 gives the schedule after nutrient management.

In both schedules, corn is planted in May and harvested in September. Rye is planted in October and harvested the next May, before the corn is planted. Both broiler litter and dairy manure is used on the crops, as well as commercial fertilizer. The only difference between the two schedules is the rate of application of broiler litter and dairy manure. Both dairy manure and poultry litter is applied in May between the rye harvest and the corn planting. Dairy manure is also applied after the corn is harvested and before the rye is planted. Only this second dairy manure application is disked into the soil. In both schedules, nitrogen fertilizer is applied to the rye in February.

Because this scenario represents an continuous cropping pattern in which manure is applied every year, soil nitrogen and phosphorus concentrations tend to build up with time. This buildup leads to increasing trends in nitrogen and phosphorus losses. To better reflect short-term nutrient losses, the simulation period was divided into four ten-year periods, and the soil profile was set to its initial condition at the beginning of each period.

Hydrology and Erosion

Nutrient management does not have a noticeable impact on the simulation of the hydrology or erosion in this rotation, so only the results of simulation of conditions before nutrient management will be discussed. Table 3.2 shows the average annual precipitation, runoff, subsurface flow, percolation, erosion. These values represent the averages for the simulated period of forty years described above. The standard deviation, minimum, and maximum values are also shown. Table 3.3 shows the average monthly precipitation, runoff, subsurface flow, percolation, and erosion.

Weather data. Daily precipitation, maximum temperature, and minimum temperature from the Staunton Wastewater Treatment Plant for the period 1949-1988 were used in the simulation. Other weather data were produced synthetically in EPIC using parameters for Monterey, VA.

The water budget. The simulated average annual precipitation is 35.6 inches. Annual precipitation ranges from 25.6 inches to 49.8 inches. Figure 3.1 shows the simulated average monthly precipitation. Precipitation tends to be lower than the monthly average of about 3 inches from November through February, and higher than the average in the summer months.

Most of water budget is accounted for by evapotranspiration. Simulated average annual evapotranspiration is 28.2 inches, or 79% of average annual precipitation. The remainder of the water budget is split roughly equally between runoff and percolation. Average annual runoff is 3.1 inches, ranging from 0.1 to 9.9 inches per year. Figure 3.2 shows the average monthly runoff. Runoff is lower in the summer because evapotranspiration keeps the soil dryer.

Average annual percolation is 3.1 inches, ranging from 0 to 9.0 inches per year. Lateral flow accounts on average for about 0.9 inches, and ranges from 0.4 to 1.4 inches per year.

Erosion. Simulated average annual soil loss in erosion is 5.5 t/ac, and ranges from a 1.3 t/ac to 21.2 t/ac. Figure 3.3 shows average monthly erosion. Erosion tends to be higher in the summer months because of the higher rainfall intensity of summer storms. Erosion is also high in October, because of decreased crop cover between the corn harvest and the growth of the rye crop.

Nutrient Losses Before Nutrient Management

Table 3.2 shows the simulated average annual nutrient losses for this rotation before nutrient management. It also shows the average annual nitrogen in corn and rye yield, as well as the annual nitrogen fertilizer inputs. The standard deviation, maximum and minimum annual values of these quantities are also shown. Table 3.4 shows the average monthly nitrogen losses and Table 3.5 show the average monthly phosphorus losses.

The nitrogen budget. Figure 3.4 shows the major components of the nitrogen budget. Before nutrient management, 586 lb/ac of nitrogen are applied annually, of which 171 lb/ac are in the form of ammonium. Approximately one-half, or 92.5 lb/ac, of this ammonium volatilizes on average annually. This is not surprising, since two of the three manure applications are surface-applied, and the third is disked five days after application.

About half of the remaining nitrogen applied is taken up by the crops. On an average annual basis, nitrogen in crop yield is 253.4 lb/ac, of which 147.3 lb is in corn silage and 106.1 lb is in rye silage. The estimated nitrogen content of the corn silage yield is in reasonable agreement with the values obtained using the approach of Meisinger and Randall, but the value for the rye silage is high. Given the targeted corn silage yield of 18 t/ac and the rye silage yield of 7.5 t/ac, nitrogen yields of 130 lb/ac and 68 lb/ac, respectively, should be anticipated.

Outside of ammonia volatilization, the largest loss of nitrogen occurs in erosion. Simulated average annual nitrogen losses in erosion are 40.9 lb/ac. Annual losses range from 8.5 lb/ac to 107.3 lb/ac. Figure 3.5 shows the simulated average monthly nitrogen losses in erosion. The seasonal pattern of nitrogen losses closely follows the seasonal pattern of erosion. The concentration of nitrogen in eroded sediment increases over the simulation period, due to the buildup of organic nitrogen in the soil. The concentration of organic nitrogen in the top three feet of soil increases by a third, from about 300 ppm to 400 ppm.

Nitrogen losses in runoff are also significant. Simulated average annual losses are 14.6 lb/ac, with annual losses ranging from 0.0 lb/ac to 59.8 lb/ac. Runoff losses do not closely follow the seasonal pattern of runoff. Figure 3.6 shows the simulated average monthly nitrogen losses in runoff. The largest losses occur in February and May. The higher losses in these months are caused by the application of fertilizer and manure in these months.

Total subsurface losses in percolation and lateral flow are not very significant. On average, only about five pounds per acre are lost per year.

Phosphorus losses. Phosphorus is applied in manure at the rate of 183 lb/ac. Figure 3.7 shows the simulated monthly average phosphorus losses. Almost all of the phosphorus is lost in eroded soil. Phosphorus losses in erosion average 16.4 lb/ac annually. They range from 3.7 lb/ac to 38.8 lb/ac. The concentration of labile phosphorus in the top one meter of soil more than doubles over a ten-year simulation period, from about 10 ppm to 24 ppm.

Nutrient Losses After Nutrient Management

Table 3.7 shows the simulated average annual nutrient losses for this rotation after nutrient management. Table 3.8 shows the average monthly nitrogen losses and Table 3.9 shows the average monthly phosphorus losses.

Nutrient management reduced nitrogen losses by 24% and reduced phosphorus losses by 36%. The bulk of the nutrient losses occurred through erosion, and nutrient management reduced nutrient losses in erosion by lowering the concentration of nutrients in the soil.

The nitrogen budget. As stated previously, nutrient management only decreases the rate of manure application in this scenario. The total nitrogen applied annually drops 31% to 406 lb/ac. Figure 3.8 shows the major components of the annual nitrogen budget. Of the 117 lb/ac of ammonium applied annually in manure, 62.3 lb/ac, more than one half, are lost through volatilization.

The average annual nitrogen content of the yield accounts for 197.3 lb/ac or 49% of the nitrogen applied in fertilizer and manure. A considerable drop in the simulated corn yield took place. Average annual nitrogen in yield decreased 30% to 102.3 lb/ac. There was a less significant drop in rye yield. The decrease in yield nitrogen was 10% for rye. Of course, the manure applications before planting corn were almost cut in half, while the manure application before planting rye and the fertilizer application during the rye growing season remained unchanged.

Erosion remained the dominant pathway for nitrogen losses after nutrient management. On average, 31.1 lb/ac were lost in erosion annually, a 24% decrease compared to the losses before nutrient management. Simulated annual losses ranged from 6.6 lb/ac to 92.3 lb/ac. Figure 3.9 shows the simulated average monthly losses of nitrogen in erosion. Just as was the case before nutrient management, the seasonal pattern of losses follows the seasonal pattern of erosion. There was less of a buildup of soil organic nitrogen under nutrient management. The concentration of organic nitrogen in the top meter of soil increased about 20% over the course of a ten-year simulation period.

Losses of nitrogen in runoff also remained significant after nutrient management. Simulated average annual losses amounted to 11.9 lb/ac. Annual losses ranged from no losses to 58.0 lb/ac. Figure 3.10 shows the simulated average monthly nitrogen losses in runoff after nutrient management. Compared to losses before nutrient management, losses in May have decreased, due to the decrease in nitrogen application in May. Losses in February remain unchanged, since there was no change in the rate of fertilizer applied in February. Overall, nitrogen losses in runoff decreased 18% with nutrient management.

Losses in lateral flow and percolation remained insignificant under nutrient management. Simulated average annual losses were again less than 5 lb/ac.

Phosphorus losses. Under nutrient management, 117 lb/ac of phosphorus are applied in manure annually. Figure 3.11 shows the simulated monthly average phosphorus losses under nutrient management. Almost no phosphorus is lost except in eroded soil. Phosphorus losses in erosion average 10.6 lb/ac annually. They range from 2.2 lb/ac to 27.7 lb/ac. Losses under nutrient management decreased by 35%. There was less of an increase in the concentration of labile phosphorus in the top three feet of soil over a ten-year simulation period under nutrient management. Soil phosphorus concentrations increased by 60%, from 10 ppm to about 16 ppm.

Sensitivity of Nitrogen Losses to Litter and Manure Application Rates

A sensitivity analysis was performed to determine the effect of litter and manure application rate on nitrogen losses. Figure 3.12 shows simulated average annual nitrogen losses as a function of the poultry litter application rate. As the rate increases, losses increase linearly. For each additional ton of broiler litter applied, there are an additional 6.8 lb/ac of nitrogen lost annually. Poultry litter contains 60 lb/t of nitrogen, of which approximately 7.5 lbs volatilizes, leaving 52.5 lb/t after volatilization. Thus approximately 13% of the nitrogen applied in the additional litter is lost. Most of the rest contributes to the buildup of organic nitrogen in the soil. It should be noted that as the rate of application of poultry litter increases, subsurface nitrogen losses in lateral flow and percolation become more significant.

Figure 3.13 shows simulated average annual nitrogen losses as a function of the spring manure application rate. The fall rate was left unchanged at 6000 gal/ac. Increasing the manure application has less impact than increasing the litter application rate. For each 1000 gal/ac increase in the manure application rate, simulated average annual nitrogen losses increase by 1.3 lb/ac. This represents approximately 9% of the additional nitrogen applied after volatilization.

The linear dependence of average annual nitrogen losses on the application rate is an expression of the fact that the simulated nitrogen losses are a linear function of application rates. In this scenario nitrogen is lost primarily through erosion, and increasing the application rate above crop needs proportionately increases the concentration of nitrogen in the soil, and therefore the amount of nitrogen in eroded soil.

Sensitivity to First Year Mineralization Rate

As explained in Chapter 2, half of the organic nitrogen estimated to mineralize in the first year after application was applied in EPIC as nitrate. A sensitivity analysis was performed to determine how this assumption affected the estimate of nitrogen reduction efficiency. Three additional pairs of simulations were made, one with all of the first year's available organic nitrogen represented as nitrate, a second with three-quarters of the available organic nitrogen as nitrate, and the third with none of the available organic nitrogen as nitrate. Each pair represented conditions before and after nutrient management. The results are shown in Table 3.11, along with the results for the base case where half of the available organic nitrogen is applied as nitrate.

There is little difference in nitrogen reduction efficiency between the base case and the case where no available nitrogen is applied as nitrate. Efficiency increases, however, as the fraction of available nitrogen applied as nitrate increases. The increase is only 1% when 75% of the available organic nitrogen is applied as nitrate, but increases by over 5% when 100% of the available nitrogen is applied as nitrate. Proportionally, there is a greater reduction in erosion losses in the simulations without nutrient management as the nitrate fraction increases. On the other hand, there is a proportionally greater increase in runoff losses. Without nutrient management, when 100% of the available nitrogen is applied as nitrate, runoff losses increase 36% over the base case. With nutrient management, runoff losses increase only 24%. Losses in percolation and lateral flow also increase to 12.6 lb/ac without nutrient management, but remain less than 5 lb/ac with nutrient management.

As more nitrogen in manure is applied as nitrate, the nitrogen in crop yield also increases in simulations both with and without nutrient management. When 75% of the available nitrogen is applied as nitrate, nitrogen in corn yield rises to 119 lb/ac. While this is still only approximately 70% of the nitrogen in corn yield without nutrient management, it is within the range reported by Meisinger and Randall. Thus increasing the mobility of available nitrogen increases crop yield without lowering the nitrogen reduction efficiency. This suggests that the low crop yields of the base case simulation with nutrient management do not invalidate the estimated nitrogen reduction efficiency.

Effect of Slope on Nutrient Losses

A sensitivity analysis was performed to determine the effect of slope on nutrient losses. The rotation both before and after nutrient management was simulated at field slopes of 4.5% and 20%. Table 3.12 shows the effect of slope on average annual runoff, lateral flow, percolation, and erosion. Table 3.13 shows average annual nitrogen losses, both before and after nutrient management, for the different simulated slopes. Table 3.14 gives the same information for phosphorus losses.

As slope increases, runoff, lateral flow, and erosion increase, and percolation decreases. The change in erosion is most dramatic. Doubling the slope approximately triples the amount of erosion. The percent change in the other quantities are less than the percent change in slope.

Since most of the nutrient losses occur in erosion, the differences in erosion at different slopes has a great impact on nutrient losses. Doubling the slope approximately doubles the total average annual nutrient losses, both before and after nutrient management. Losses in erosion more than double. Nitrogen losses in runoff and lateral flow also increase, while nitrogen losses in percolation decrease. Losses of phosphorus in runoff and percolation do not change with slope. The nutrient reduction efficiency does not change dramatically with changes in slope, despite the large increases in losses with slope. Nitrogen reduction efficiency ranges from 26% to 25% as the sloe ranges from 4.5% to 20%, and phosphorus reduction efficiency ranges from 39% to 36% over the same range in slope. Nutrient management does not effect the amount erosion, but it does lower the concentration of organic nitrogen and phosphorus in the soil, and the decrease is roughly proportional to the application rates of the nutrients.

Effect of Soil Type

The effect of soil type on nutrient losses and nutrient reduction efficiency was examined by performing simulations of the same farm schedules, both before and after nutrient management, on two additional soils: a Timberville silt loam and a Nixa very cherty silt loam. The Timberville silt loam, like the Frederick silt loam, belongs to hydrologic group B. In contrast to the Frederick soil, its slope ranges from 0 to 7%. The Nixa very cherty silt loam belongs to hydrologic group C, and its slope ranges from 0 to 25%. Not only is it less permeable that the other two soils, but it is characterized by its high density of large cherty rock fragments.

Table 3.15 shows the simulated average annual runoff, subsurface flow, percolation, and erosion for these three soils. The results can be explained by slope, hydrologic group, and rock fragment density. In these simulations, the slope of the Frederick and Nixa soils were set at 10%, and the slope of the Timberville soil was set at 3.5%. There is more runoff and more erosion from the Frederick soil than the Timberville soil, because the Frederick soil's slope is greater. The erosion from the Timberville soil is less than 20% of the erosion from the Frederick soil. There is more runoff from the Nixa soil than the other two soils, because it belongs to hydrologic group C rather than B. The Nixa soil has 84% more runoff than the Frederick soil and more than double the runoff of the Timberville soil. Since EPIC reduces the erosion capacity of a soil with a high density of large rock fragments, the Nixa soil has less erosion than the Frederick soil, almost as little as the Timberville soil on a much smaller slope. Both lateral flow and percolation are greater on the Timberville and Nixa soils than the Frederick soil. More percolation occurs on the Nixa soil because of lower evapotranspiration due to lower crop yields.

For the most part, simulated nitrogen losses follow the pattern of the simulated hydrology and erosion. Table 3.16 shows the simulated average annual nitrogen losses before and after nutrient management and the nitrogen reduction efficiency for each soil.

In general, the Timberville soil has less losses both before and after nutrient management, because it has less runoff and less erosion. With the decrease in erosion, a greater proportion of nitrogen losses occur in runoff and subsurface flow. The nitrogen reduction efficiency of nutrient management on the Timberville soil is 3% higher than the efficiency of nutrient management on the Frederick soil.

Runoff losses dominate the simulations on Nixa soil. These are reduced about 12% by nutrient management. The nitrogen reduction efficiency of nutrient management is higher on the Nixa soils than the other two soils. The high nitrogen reduction efficiency on the Nixa soil is due in part to the reduction of subsurface losses, which drop from 24.6 lb/ac to 11.4 lb/ac, or over 50%. Crop yields are lower on the Nixa soil. Less nitrogen is used by the crops and more remains available in the root zone to be transported in percolation or subsurface flow.

Table 3.17 shows simulated average annual phosphorus losses and the phosphorus reduction efficiency for each of the soils. Erosion remains the dominant pathway for phosphorus loss, and, for the same management schedule, the losses for each soil are roughly proportional to the erosion on each soil. The phosphorus reduction efficiency is about the same for each soil, because the concentration of phosphorus in the eroded soil is proportionally reduced by the reduction in phosphorus application under nutrient management.

Chapter Four

Second Virginia Scenario: Poultry Operation in Limestone Region

Scenario Description

The second Virginia scenario represents a continuous fescue/orchard grass hay crop on a turkey farm in the limestone region of the Shenandoah Valley. Turkey litter is applied annually. The grass is harvested three times annually, in May, July and October. As in the first Virginia scenario, the soil is a Frederick silt loam with a 7-15% slope, simulated as a 10 % slope. Table 4.1 gives the schedule of farming operations for this scenario.

In this scenario no farm schedules represent conditions before or after nutrient management. The Virginia Department of Conservation and Recreation suggested that nine alternative schedules to the one given in Table 4.1 be simulated. These alternative scenarios would represent changes in (1) the timing of turkey litter application, (2) the rate of litter application, and (3) the affect of slope on nutrient losses. Table 4.2 lists the nine alternative scenarios. In the base case scenario, represented in Table 4.1, 4 t/ac of turkey litter are applied April 1. The first four alternative scenarios represent applications at the same rate in January, June, October, and November. The fifth alternative scenario splits the four ton application between April and August. This is the scenario favored by the Department of Conservation and Recreation. The next two alternative scenarios apply litter in April but at different rates: The sixth scenario applies 5 t/ac while the seventh applies 3 t/ac. Scenarios 8 and 9 apply 4 t/ac on April 1 but change the slope of the field. The field in the eighth scenario has a 2-7% slope while the field in the ninth scenario has a 15-25% slope. For the purposes of the simulation, they were set to 4.5% and 20% slopes, respectively.

Since the litter is always applied to the surface without incorporation, the potential for the buildup of nitrogen and phosphorus in the soil surface is great. To better quantify short-term losses, four ten-year simulations were run for each scenario, and the summary statistics were compiled from the total forty years of simulation, just as in the first Virginia scenario.

Hydrology and Erosion

The same weather data was used in these simulations as was used in the first Virginia scenario. Consequently, simulated precipitation follows the pattern described in the first simulation. See the discussion in that section for details.

Tables 4.3 through 4.12 show the simulated average annual precipitation, runoff, subsurface flow, percolation, evapotranspiration, and erosion for the Base Case scenario and the nine alternative scenarios, respectively. For the base case and the first seven scenarios, which represent a 7-15% slope, and which were modeled with a slope of 10%, the simulated hydrology does not vary significantly, so only the base case scenario will be discussed quantitatively. Evapotranspiration consumed 81%, or 28.8 inches of 35.6 inch average annual precipitation. Percolation was the next largest component of the water budget, averaging around 4.5 inches or 13% of average annual precipitation. Subsurface flow accounted for 1.1 inches or about 3% of the budget. Runoff from pasture tends to be low, and simulated runoff using the Curve Number Procedure, even when corrected for slope, tends to be minimal. The simulated average annual runoff accounts for just less than 1 inch or 3% of the water budget. Figure 4.1 shows the average monthly runoff, lateral flow, and percolation for the base case scenario. Runoff, lateral flow, and percolation all tend to be higher in the winter than the summer. Runoff is noticeably higher in February, though it still much smaller than the average monthly percolation for that month.

Annual erosion is minimal in these first eight simulations, with losses no higher than 0.3 t/ac. Given that grass forms a good soil cover, this is not unexpected. In general, erosion does not take place in December, January, and February, and is evenly divided over the remaining months.

Alternative scenarios 8 and 9 change the slope of the field. Changes in slope effect runoff, erosion, subsurface flow, and percolation. Increasing the slope increases erosion. There is less than 0.1 t/ac average annual erosion in Alternative Scenario 8, when the slope is reduce to 4.5%, and more erosion, 0.3 t/ac on an average annual basis, when the slope is increased in Scenario 9 to 20%.

Increasing the slope directly increases runoff through EPIC's slope correction factor for the Curve Number Procedure. The change is slight. Simulated average annual runoff for Scenario 9 increases to 1.1 inches, while average annual runoff in Scenario 8 decreases to 0.8 inches. Changing the amount of runoff changes the amount of water available for lateral flow and percolation, but changing the slope also changes the amount of lateral flow directly. Increasing the slope increases the volume of lateral flow, which also decreases the water available for percolation. In Scenario 9, where the slope is increased, lateral flow increases by over 70% from the base case, and percolation decreases by about 30%. In Scenario 8, where the slope is decreased, lateral flow drops by over 50% and percolation increases by over 20%.

The Nitrogen Budget

Nutrient losses from these simulations are low, especially when compared to the more complex rotations simulated in this project. The bulk of the nitrogen applied annually is either lost in ammonia volatilization, taken up by the crop, or builds up in the soil. Tables 4.3-4.12 give the simulated average annual nitrogen application rate, crop uptake, and nitrogen losses for the scenarios. Nitrogen losses are also summarized for all scenarios in Table 4.13. The nitrogen budget for individual scenarios will be discussed below under three headings: (1) differences in the nitrogen budget due to differences in the timing of the application, (2) differences in the nitrogen budget due to differences in the rate of application, and (3) differences in the nitrogen budget due to differences in field slope.

Differences in the nitrogen budget due to changes in the timing of litter application. The first five scenarios differ from the base case in the timing of the litter application. In each scenario, 4 t/ac of litter are applied each year, which contains 252 lb/ac total nitrogen, of which 60 lb is in the form of ammonium. Because the litter is surface-applied, more than half of the ammonium is lost through volatilization.

Average annual nitrogen content of the crop yield ranges from 100.8 to 111.3 lb/ac, which is within the range for target yield of 3.5 t/ac, as determined by the methods of Meisinger and

Randall. Crop yield thus accounts for approximately 40-45% of the applied nitrogen. The inter-annual variability with a scenario is greater than the variability in crop yield between the scenarios.

Total nitrogen losses, on the other hand, account for 3% or less of the nitrogen applied annually in turkey litter. Table 4.13 gives the average annual loss for each scenario as a percent of Base Case losses. Average annual losses range from 4.5 lb/ac in the Base Case to 7.7 lb/ac in Scenario 1. The next highest average annual losses, however, are only 5.7 lb/ac, which occurred in Scenario 2. Thus the range of losses is quite narrow. With the exception of Scenario 1, all scenarios which differ only in timing are within 25% of the Base Case. Reporting the percentage can be misleading, since a 25% increase in a small amount is still a small amount, but it does give a way to quickly compare the quantity of losses from each scenario.

Nitrogen losses in erosion vary even less than overall losses. They range from 1.5 lb/ac in Scenarios 3 and 4 to 1.8 lb/ac in the Base Case and Scenario 1. With the exception of Scenario 1, runoff losses account for only a small fraction of total losses, ranging across scenarios from 0.1 to 0.4 lb/ac. The larger loss of nitrogen in runoff in Scenario 1, averaging 2.9 lb/ac annually, is because the litter is applied in Scenario 1 on January 20, and runoff is significantly higher on average in February. With the exception of Scenario 1, more than half of the total nitrogen lost in the scenarios is lost in percolation or lateral flow, with the bulk of these losses in lateral flow.

It needs to be explained why the timing of litter application does not have a greater impact on nitrogen losses. Splitting the application, as done in Scenario 5, would have a greater impact, if the potential for nitrogen loss were greater in the months between April and August. During this period, however, runoff, percolation, and lateral flow are small compared to the overall water budget. Moreover, less nitrogen is taken up by the fescue after August than in the peak growth period in the spring, so some of the nitrogen applied in August may run the risk of being lost in the fall and winter. It may also seem that Scenarios 3 and 4, which have fall applications, should run a more significant risk of nitrogen loss through percolation or subsurface flow. Annual percolation is quite variable, however, and may not always occur in quantities sufficient to leach the applied nitrogen out of the soil profile.

In the course of a ten-year simulation, there is a 16-20% increase in the concentration of organic nitrogen in the top three feet of soil, from approximately 300 ppm to 355-360 ppm. Much of this buildup is confined to the top one-quarter of an inch. Concentrations in this surface layer increase eight-fold, from approximately 1000 ppm to over 8000 ppm. This buildup occurs because the turkey litter is applied to the surface, and no tillage operation mixes the surface layer with the layers below it.

Differences in the nitrogen budget due to changes in the rate of litter application. Scenario 6 raises the rate of litter application to 5 t/ac while Scenario 7 lowers it to 3 t/ac. Scenario 6 thus applies 315 lb/ac of nitrogen per year, of which 75 lb is in the form of ammonium, while Scenario 7 applies 189 lb/ac of nitrogen per year, of which 45 lb is in the form of ammonium. In Scenario 6, 45 lb/ac of ammonia nitrogen, or 60%, are volatilized each year, and roughly the same percentage, 62%, or 28 lb/ac, is volatilized per year in Scenario 7. Roughly a constant percentage, 60%, of the applied ammonium nitrogen is volatilized.

The nitrogen content in the yield increased 15% over the base case when an additional ton of litter is added in Scenario 6. In other words, approximately 25% of the additional nitrogen can be accounted for by increased yields. On the other hand, there was a 17% decrease in the nitrogen content in the yield in Scenario 7, when litter application was reduced by one ton from the Base Case. In increasing the application rate from 3 t/ac to 4 t/ac, 30% of the increase in nitrogen went into increased yields.

As might be expected, total nitrogen losses in Scenario 6 increased by 62% over the Base Case, and dropped by 36% in Scenario 7. Total average annual nitrogen losses were 7.3 lb/ac in Scenario 6, still a relatively small number. Losses increased in erosion, lateral flow, and percolation. A small drop in losses in each of these categories accounts for the 1.6 lb/ac drop to 2.9 lb/ac in Scenario 7.

The nitrogen losses from these scenarios is relatively small, and thus the difference in losses may seem insignificant. When litter is applied at even higher rates, significant losses can occur. Figure 4.2 shows total average annual nitrogen losses for litter application rates in the range between 3 - 10 t/ac. As the application rate increases, the annual nitrogen loss in erosion increases slowly, but the loss in percolation and lateral flow increases significantly. Doubling the rate more than doubles nitrogen losses. At an application rate of 8 t/ac, average annual nitrogen losses are over 20 lb/ac, and at 10 t/ac, losses are over 40 lb/ac.

Differences in the nitrogen budget due to changes in the slope of the field. Differences in field slope have a significant impact on nitrogen losses, although losses remain relatively small. As mentioned previously, increasing the slope can be expected to increase erosion, runoff, and lateral flow, and decrease percolation. Nitrogen losses in these pathways can be expected to increase or decrease accordingly. When the slope is doubled to 20% in Alternative Scenario 9, nitrogen losses double to 9.2 lb/ac, compared to the Base Case. Losses in erosion, runoff and lateral flow more than double over the Base Case, while losses in percolation decrease. In Scenario 8, where the field slope is reduced to 4.5%, average annual total nitrogen losses decrease to 2.8 lb/ac, or 62% of the Base Case's losses. Losses in erosion and lateral flow decrease, but losses in percolation increase.

Phosphorus losses

Average annual phosphorus losses are minimal. Table 4.14 summarizes average annual phosphorus losses for the ten scenarios. In all scenarios except Scenario 9, less than 1 lb/ac is lost on average per year. In Scenario 9, 1.7 lb/ac are lost. Almost all of the phosphorus is lost in erosion, and the fact that about three times as much erosion occurs in Scenario 9 as in the other scenarios explains that scenario's higher losses.

There is an increase in the concentration of labile phosphorus in the soil over the course of a ten-year simulation period. The concentration of phosphorus in the top three feet of soil increases on average 60%, from 10 ppm to 16 ppm. Just as with soil organic nitrogen, the labile phosphorus concentration increased even more dramatically in the top one-quarter inch of soil, from 20 ppm to 920 ppm on average, more than a forty-fold increase.

The Sensitivity of Nitrogen Losses to First Year Mineralization Rate

A sensitivity analysis was performed to determine if the fraction of available organic nitrogen applied as nitrate affected overall results. All ten scenarios were run with (1) none of the available organic nitrogen applied as nitrate, (2) three-quarters of the available nitrogen applied as nitrate, and (3) all of the available nitrogen applied as nitrate. The results are shown in Tables 4.15, 4.16, and 4.17, respectively, and should be compared to Table 4.13, where half of the available organic nitrogen was applied as nitrate.

Several trends can be noted. As the fraction of nitrogen applied as nitrate increases, losses increase. For the most scenarios, average annual losses remain less than 10 lb/ac at the 75% nitrate level and rise to around 10 lb/ac only when 100% of the available nitrogen is applied as nitrate. As might be expected, Scenarios 2, 6, and 9 show slightly higher losses. As the fraction of nitrogen applied as nitrate increases, losses in runoff, percolation, and lateral flow increase, and losses in erosion decrease, as should be expected, since less organic nitrogen, which is only lost in erosion, is being applied.

The differences in losses among the scenarios do not strictly increase with the increase in the amount of available nitrogen applied as nitrate When none of the available nitrogen is applied as nitrate, there is less difference in losses among the scenarios. When no available nitrogen is applied as nitrate, scenarios 3 and 4 show a slight decrease in losses compared to the Base Case. It should be noted, however, that the nitrogen content of the yield has dropped considerably at this level of nitrate application. Nitrogen in the yield dropped 35% in the Base Case, to 72.4 lb/ac on an annual basis. Yields increase as the percent of nitrogen applied as nitrate increases. Base Case nitrogen content in yield increases to 124.7 lb/ac, a 12% increase, when the nitrate application level is 75%, and to 140.7 lb/ac , a 26% increase, when the nitrate application level is 100%.

One trend does seem surprising: As the nitrate application level increases, the importance of slope decreases. That is, the difference between the Base Case and Scenarios 8 and 9, expressed as a percentage of the Base Case, decreases as the nitrate application level increases. Scenario 1 shows the opposite trend. As the nitrate application level increases, runoff losses also increase, and the difference in nitrogen losses between the Base Case and Scenario 1 increases. The effects of different levels of nitrate application seem minor, however, compared to the overall impression of the results of this set of simulations: nitrogen losses are relatively low and the differences between scenarios is relatively small.

Effect of Soil Type

The effect of soil type was examined by simulating on two additional soils: a Timberville silt loam and a Nixa very cherty silt loam. These same two soils were used for comparison in the first Virginia scenario. The Timberville silt loam, like the Frederick silt loam, belongs to hydrologic group B. In contrast to the Frederick soil, its slope ranges from 0 to 7%. The Nixa very cherty silt loam belongs to hydrologic group C, and its slope ranges from 0 to 25%. Not only is it less permeable that the other two soils, but it is characterized by its high density of large cherty rock fragments.

Hydrology and erosion. Table 4.18 shows the simulated average annual hydrology and nutrient losses for Base Case Scenario on the Timberville soil, and Table 4.21 shows the same statistics for the Base Case on the Nixa soil. Just as in the first Virginia scenario, the results can be explained by slope, and hydrologic group. The slope of the Nixa soil was simulated at 10%, the same slope as the Base Case for the Frederick soil, and the slope of the Timberville soil was simulated at 3.5%. There is more runoff from the Frederick soil than the Timberville soil, because the Frederick soil's slope is greater. There is more runoff from the Nixa soil than the other two soils, because it belongs to hydrologic group C rather than B. There is more percolation from the Timberville soil than the Frederick soil, because the smaller slope produces less runoff and less lateral flow. Surprisingly, there is more percolation from the Nixa soil than the Frederick soil as well. This is due to the decrease in evapotranspiration, associated with lower crop yield, which increases percolation despite the increase in runoff. On all three soils, erosion is negligible.

Nutrient losses on the Timberville silt loam. Table 4.18 shows the summary statistics for nutrient losses for the Base Case on the Timberville soil. Table 4.19 compares the simulated average annual nitrogen losses for the Base Case and Alternative Scenarios 1 through 7. Table 4.20 compares the average annual phosphorus losses for the same scenarios. Scenarios 8 and 9 were not run on the Timberville soil because its slope only ranges from 2 to 7 %.

Nutrient losses remain minimal when the scenarios are run on the Timberville soil. Phosphorus losses are negligible, because erosion is the primary pathway for phosphorus losses, and it is negligible. Average annual nitrogen losses are slightly higher for simulations on the Timberville soil than for the corresponding simulations on the Frederick soil. Nitrogen losses in erosion, runoff, and lateral flow are lower, but nitrogen losses in percolation increase more than five-fold for all scenarios, despite the fact that the increase in percolation is not as great. In the Base Case, for example, average annual percolation is 4.5 in /ac on the Frederick soil, compared to 7.7 in/ac on the Timberville soil, a 71% increase. In contrast nitrogen losses in percolation are 0.7 lb/in on the Frederick soil and 4.8 lb/ac on the Timberville soil, an increase of almost 600%.

Nutrient losses on the Nixa cherty silt loam. Table 4.21 shows the summary statistics for nutrient losses for the Base Case on the Nixa soil. Table 4.22 compares the simulated average annual nitrogen losses for the Base Case and Alternative Scenarios. Table 4.23 compares the average annual phosphorus losses for the same scenarios.

Phosphorus losses remain negligible for the simulations on the Nixa soil. Nitrogen losses, however, have increased significantly. Average annual total nitrogen losses are above 10 lb/ac for all scenarios except Scenario 7, where only 3 t/ac of turkey litter is applied annually. Nitrogen losses in erosion decrease, but they increase in runoff, lateral flow, and percolation. The greatest difference is in percolation losses. Just as was the case for the Timberville soil, the difference in nitrogen losses in percolation is disproportional to the difference in percolation. In the Base Case, average annual percolation is 4.5 inches on the Frederick soil and 7.3 inches on the Nixa soil, a 62% increase. In contrast nitrogen losses in percolation are 0.7 lb/ac on the Frederick soil and 7.3 lb/ac on the Nixa soil, an increase of over 900%.

Because percolation losses are dominant, variation in slope do not have as much effect in Scenarios 8 and 9 on the Nixa soil. In Scenario 8, decreasing the slope decreases total nitrogen losses by only 5%, because lower losses in erosion, runoff, and lateral flow are almost balanced by greater losses in percolation. Increasing the slope in Scenario 9 increases losses by 19% on the Nixa soil. Losses in percolation decreased while the losses in other pathways increased. On the Frederick soil, the same increase in slope doubled total average annual nitrogen losses.

Chapter Five

First Pennsylvania Scenario: Swine and Dairy Operation in Ridge and Valley Region

Scenario Description

The first Pennsylvania scenario represents a nine-year rotation, mostly corn and alfalfa, on a swine and dairy operation in the Ridge and Valley Region. This operation is typical of those found in northern Dauphin County. Both hog manure and dairy manure are used as fertilizer. The soil represented is a Calvin-Leck Kill shaly silt loam with a 3-8% slope. In the simulations, data representing a Calvin soil was used, with a 5% slope. The simulation period was 63 years, or seven full nine-year rotation periods.

Table 5.1 shows the schedule of farm operations when dairy manure is used before nutrient management. The same schedule is used before nutrient management when hog manure is applied. Corn silage is grown in the first year. Rye is grown between the first and second year. Grain corn is grown the second and third years. Corn silage is again grown in the forth year. Barley is grown, beginning in the fall of the fourth year until the summer of the fifth year. Alfalfa is planted in the summer of the fifth year and remains for the last four years of the rotation. It is cut twice in the sixth year and three times in the remaining years.

Manure is applied before each corn planting, and before planting both rye and barley. The manure is incorporated into the soil with a disk or chisel plow, except for the application prior to planting alfalfa, where a moldboard plow is used. Manure is also applied to the alfalfa each September, but is not incorporated. The corn crop receives inorganic starter fertilizer containing both nitrogen and phosphorus. It also receives nitrogen sidedress fertilizer one month after planting. In the eighth and ninth year, the alfalfa receives phosphorus fertilizer.

Table 5.9 shows the schedule of farm operations, when dairy manure is applied after nutrient management. The schedule of operations remains the almost same. The major difference is the reduction in the rate of both organic and inorganic fertilizer applications. In addition, no sidedress fertilizer is applied to the first year of corn, and the manure applied before planting the alfalfa is incorporated by disk rather than by moldboard plow. After nutrient management, when hog manure is used, the rate of application of the manure is also reduced, and no starter or sidedress fertilizer is applied to the corn.

Hydrology and Erosion

Nutrient management does not have a large impact on the simulation of hydrology or erosion in this rotation. The results from the simulation representing the application of dairy manure before nutrient management are typical of the other scenarios as well. Table 5.2 shows the simulated average annual precipitation, runoff, lateral flow, percolation, and erosion, as well as the standard deviation, and maximum and minimum values for these quantities. Table 5.3 shows their average annual values for each rotation year.

Weather data. Daily precipitation, maximum temperature, and minimum temperature from the Harrisburg Wastewater Treatment Plant for the period 1926-1991 were used in the simulation. Other weather data were produced synthetically in EPIC using weather parameters for Harrisburg.

The water budget. The simulated average annual precipitation is 39.1 inches. Annual precipitation ranges from 27.3 inches to 59.3 inches. Figure 5.1 shows the simulated average monthly precipitation. While the variation in monthly precipitation is not great, precipitation tends to below average from October through February and above average in May, June, and July.

Evapotranspiration accounts for more than half the water budget, or 21.5 inches annually on average. Percolation accounts for more than one-quarter of the water budget, or 11.8 inches per year, and runoff account for 5.0 inches per year or about one-eighth of average annual precipitation. Lateral flow accounts for less than one inch per year on average of the water budget.

There is a great deal of variability in simulated average annual runoff and percolation. Annual runoff ranges from 0.6 inches to 20.8 inches, which annual percolation ranges from 4.8 to19.9 inches. Some of this variability can be explained by the rotation schedule or seasonal effects. As Table 5.3 shows, average annual runoff is higher in Years 2, 3, 4 of the rotation. Figure 5.2 shows the simulated average monthly runoff over the course of the rotation. Average monthly runoff is higher when corn, rye, or barley is grown, and declines as alfalfa is established. Runoff tends to higher in the winter than the summer, but the highest monthly averages tend to occur in late spring while corn is being established.

There is less variability among the simulated average annual percolation for different rotation years, as Table 5.3 shows. Seasonal effects tend to dominate other trends. Figure 5.3 shows the average monthly percolation over the nine-year rotation. Percolation tends to drop during the summer, when evapotranspiration is highest, and peaks in winter and early spring. Winter peaks tend to be larger when alfalfa, barley, or rye are present.

Erosion. Simulated average annual soil loss in erosion is 0.9 t/ac, and ranges from no erosion to 4.6 t/ac. Average annual erosion varies with rotation year. As Table 5.3 shows, erosion is higher in the first five years of the rotation than in the last four years after the alfalfa has been established. Figure 5.4 shows the simulated average monthly erosion over the course of the nine-year rotation. In addition to the low erosion losses during the years when alfalfa is grown, the most prominent pattern is the higher erosion losses during the summer months.

Nutrient Losses Before Nutrient Management

Table 5.2 shows the simulated average annual nutrient losses for this rotation when dairy manure is used before nutrient management. It also shows the average annual yield for each crop, and the average annual nitrogen fertilizer inputs. Table 5.4 shows the simulated average annual nitrogen losses by rotation year. Table 5.5 shows the same statistics for phosphorus. Table 5.6 shows the simulated annual average nutrient losses, crop yields, and fertilizer inputs when hog manure is used before nutrient management. Table 5.7 shows nitrogen losses by rotation year, while Table

5.8 shows phosphorus losses by rotation year.

The nitrogen budget when dairy manure is used. Figure 5.5 shows the major components of the nitrogen budget when dairy manure is used before nutrient management. On an annual basis, 320.2 lb/ac of nitrogen are applied in manure and fertilizer. Twenty-three percent, or 72.9 lb/ac, are applied as ammonium. A little more than half of the ammonium, 38.2 lb/ac, volatilizes, on an average annual basis. The inter-annual variability in volatilization reflects the variability of ammonium applied in the rotation cycle.

The nitrogen harvested in crop yield is 153.1 lb/ac annually. The simulated average annual nitrogen yield is given for each crop in Table 5.2. The average annual nitrogen content of the corn yield is 116.1 lb/ac, of the rye yield is 24.5 lb/ac, of the barely yield is 62.7 lb/ac, and of the alfalfa yield is 206.7 lb/ac. The crops account for more than half of the nitrogen input as fertilizer, but nitrogen fixation by the alfalfa must also be included in nitrogen inputs. Simulated average annual nitrogen fixation is 91.5 lb/ac, averaged over all years of the rotation cycle, not just the years that alfalfa is present. With the addition of nitrogen fixation to the nitrogen inputs, the nitrogen in crop yield account for 41% of the nitrogen.

Nitrogen losses in percolation account for the largest share of environmental losses. On an annual basis, an average of 106.0 lb/ac are lost in percolation. Annual losses range from 4.5 lb/ac to 233.8 lb/ac. The simulated average annual losses in erosion, runoff, and lateral flow are 17.8 lb/ac, 7.8 lb/ac, and 5.4 lb/ac, respectively. Although losses of nitrogen in runoff and erosion are much smaller than the losses in percolation when averaged over the whole rotation, the losses in erosion and runoff constitute a larger share of losses in some rotation years. As Table 5.4 shows, erosion and runoff losses are higher on average and form a larger share of total losses in the first four years of the rotation cycle. Figure 5.6 shows the simulated average monthly nitrogen losses in erosion and Figure 5.7 shows the average monthly nitrogen losses in runoff. As might be expected, the pattern of nitrogen losses in erosion and runoff follow the pattern of erosion and runoff in the rotation.

This is less true for nitrogen losses in percolation. Nitrogen losses in percolation is not strictly proportional to the quantity of percolation on an average annual basis. Year 9, the year with the largest average annual percolation, has one of the lowest average annual nitrogen losses. Figure 5.8 shows the simulated average monthly nitrogen losses in percolation and subsurface flow over the rotation. In general, the seasonal pattern of percolation is reflected in the monthly nitrogen losses in percolation: losses are higher in the winter and early spring when percolation is higher. On an average monthly basis, however, the highest losses do not occur when percolation is highest.

The organic nitrogen concentration in the soil profile increases from approximately 550 ppm to 970 ppm, a 76 % increase over the course of the simulation. The rate of increase in the concentration of organic nitrogen averages less than 1% per year. It does induce, however, an increasing trend in nitrogen losses in erosion, which is small compared to nitrogen losses overall.

The nitrogen budget when hog manure is used. Figure 5.9 shows the major components of the nitrogen balance when hog manure is used. Although the same amount of hog manure is used in each application as dairy manure (30 t/ac), hog manure has a higher concentration of nitrogen, 14 lb/t, and a higher percentage of ammonium nitrogen, 50%, than dairy manure. As a result, on an average annual basis, 534.6 lb/ac of nitrogen are added in the rotation using hog manure before nutrient management. Almost half of this, 47%, is in the form of ammonium. As Table 5.6 shows, 134.3 lb/ac of nitrogen are lost through ammonia volatilization on an average annual basis, which is about half of the nitrogen in ammonium form applied each year.

Compared to the simulation using dairy manure, crop yields did not substantially increase when hog manure was used, despite the fact that nitrogen fertilizer inputs increased by about two-thirds. The average annual nitrogen content in crop yield is 154.9 lb/ac, compared to 153.1 lb/ac when dairy manure is used. The amount of nitrogen fixed on an average annual basis, 87.3 lb/ac, is slightly lower than the amount fixed when dairy manure is used. Greater nitrogen inputs are reflected, however, in greater environmental losses. As Table 5.6 shows, nitrogen losses in runoff and erosion do not increase greatly. On an average annual basis, 20.4 lb/ac of nitrogen are lost in erosion and 10.8 lb/ac are lost in runoff. On the other hand, subsurface losses almost double when hog manure is used. Simulated average annual nitrogen losses in lateral flow are 9.5 lb/ac and the average annual nitrogen loss in percolation is 191.8 lb/ac. The ammonium nitrogen in hog manure is quickly turned into nitrate if it does not volatilize. This nitrate is lost in percolation if it is not taken up by the crop.

Table 5.7 shows the simulated average annual nitrogen losses for each rotation year. In general nitrogen losses follow the same pattern when hog manure is used as they did when dairy manure is used. Nitrogen losses in erosion and runoff are correlated with the quantity of erosion and runoff. Percolation losses are not.

Although more nitrogen is applied when hog manure is used, disproportionally less is applied as organic nitrogen. This explains why erosion losses do not increase in proportion to the increase in nitrogen applied in fertilizer. When hog manure is used without nutrient management, the concentration of organic nitrogen in the soil increases from approximately 550 ppm to 1070 ppm over the course of the simulation, an increase of 95%. When hog manure is used, the final soil organic nitrogen concentration is only 100 ppm greater than the final concentration when dairy manure is used.

Phosphorus losses. Table 5.2 shows the simulated average annual phosphorus losses when dairy manure is used without nutrient management. Table 5.5 shows the average annual losses for each rotation year. Table 5.6 shows the simulated average annual phosphorus losses when hog manure is used without nutrient management. Table 5.8 show the average annual losses for each rotation year.

In terms of elemental phosphorus, 54.9 lb/ac are applied on average annual when dairy manure is used without nutrient management. Total average annual losses of phosphorus are 3.5 lb/ac, or 6% of the applied phosphorus. Over two-thirds of the phosphorus is lost in erosion; most of the rest is lost in runoff. On average, more phosphorus is lost in erosion and runoff in the years when corn is grown than in the years when alfalfa is grown. Labile phosphorus concentrations in the soil increase by almost 200% in the course of the 63-year simulation period, from 11.1 ppm to 29.2 ppm.

Hog manure is richer in phosphorus than dairy manure. Dairy manure has 1.3 lb/t phosphorus, on an elemental basis, but hog manure has 4.8 lb/t, almost four times as much. When hog manure is used without nutrient management, 182.8 lb/ac of phosphorus are applied annually on average. The simulated average annual phosphorus loss is 9.3 lb/ac. Approximately two-thirds of this is lost in erosion; most of the rest is lost in runoff. Just as in the simulation with dairy manure, erosion and runoff losses tend to occur in the years when corn is grown and more erosion and runoff occurs.

When hog manure is used without nutrient management, average annual phosphorus losses are still only 5% of the phosphorus applied annually. Most of the applied phosphorus remains in the soil. In the course of the simulation, the concentration of phosphorus in the soil profile rises from 16 ppm to 116 ppm. This increase in soil phosphorus causes increased losses in erosion and runoff as the simulation progresses.

Nutrient Losses After Nutrient Management

Rate of manure and fertilizer application after nutrient management. Table 5.9 shows the farm operations schedule for the scenario when dairy manure is used after nutrient management. The rate of application of dairy manure is reduced from 30 t/ac to 20 t/ac per application. The application rates of both nitrogen and phosphorus in starter fertilizer for corn are reduced by half. The application rate of sidedress fertilizer is also reduced, from 50 lb/ac to 30 lb/ac.
The application rate of hog manure is reduced by half, to 15 t/ac per application. The use of starter and sidedress fertilizer is eliminated. The only inorganic fertilizer applications in the rotation are the two phosphorus applications on alfalfa in the eighth and ninth years.

The nitrogen balance using dairy manure after nutrient management. Table 5.10 shows the simulated average annual nitrogen losses when dairy manure is used after nutrient management. Figure 5.10 shows the major components of the annual nitrogen budget. On an average annual basis, the amount of nitrogen applied in dairy manure and fertilizer is 207.9 lb/ac, a reduction of 35%. About 23% of the nitrogen, or 48.6 lb/ac, is applied as ammonium. About half of the applied ammonium, 25.5 lb/ac, is volatilized per year.

Simulated crop yields fall slightly under nutrient management. The nitrogen content in corn yield declined from 116.1 lb/ac to 106.6 lb/ac, or an 8% drop. The nitrogen content in the barley yield declined by 13%, from 62.7 lb/ac to 54.3 lb/ac, and rye declined by 15%, from 24.5 lb/ac to 20.8 lb/ac. The simulated average annual nitrogen content in alfalfa yield declined by about a pound per acre, from 206.7 lb/ac to 205.6 lb/ac. There was a slight increase in average annual nitrogen fixation, from 91.5 lb/ac to 96.2 lb/ac.

Environmental nitrogen losses, however, declined by 43%, from an annual average 137.1 lb/ac total nitrogen losses to 78.4 lb/ac. Most of the decline occurred in percolation losses. The simulated average annual nitrogen losses in percolation declined 48%, from 106.0 lb/ac to 55.1 lb/ac. The decline in nitrogen losses in erosion, runoff, and lateral flow were smaller, 2.5 lb/ac, 2.7 lb/ac, and 2.4 lb/ac, to 15.3 lb/ac, 5.1 lb/ac, and 3.0 lb/ac, respectively. Table 5.11 shows the simulated average annual nitrogen losses by rotation year. In general, only the magnitude, and not the timing of losses, is changed by nutrient management. One exception to this rule is the decrease in nitrogen losses in lateral flow and percolation in the winter and early spring when rye and barley are grown. Figure 5.11 shows the average monthly nitrogen losses in lateral flow and percolation when dairy manure is used after nutrient management. The pattern of losses is similar to that shown in Figure 5.8, except for disproportionate decrease in losses that occurs between Years 1 and 2 and Years 4 and 5. This disproportionate decrease can be traced to the reduction in the rate of manure application prior to planting the rye and barley.

Over the course of the simulation, the concentration of organic nitrogen in the soil increases by about half, from 550 ppm to 840 ppm. This is about 130 ppm less than the increase before nutrient management.

The nitrogen balance using hog manure after nutrient management. Table 5.13 shows the simulated average annual nitrogen losses when hog manure is used in the rotation under nutrient management. Figure 5.12 shows the major components of the annual nitrogen budget. Under nutrient management, 256.7 lb/ac of nitrogen are applied in hog manure on average annually, of which 128.4 lb/ac, half, is in the form of ammonium. More than half of the ammonium, 67.9 lb/ac on average, volatilizes each year.

The nitrogen content in corn yield, rye yield, barley yield, and alfalfa was 105.4, 22.6, 57.7, and 205.7 lb/ac, respectively. Yields declined about the same magnitude as they did when dairy manure is used. Average annual nitrogen fixation increased from 87.3 lb/ac to 95.5 lb/ac. The biggest change occurred in the simulated nitrogen losses. Total nitrogen losses declined by 62 %, from 232.5 lb/ac to 88.3 lb/ac on an average annual basis. Percolation losses declined by almost two thirds, from 191.8 lb/ac to 65 lb/ac, while losses in runoff and lateral flow declined by more than one-half, from 10.8 lb/ac and 9.5 lb/ac, to 5.1 lb/ac and 3.6 lb/ac, respectively. The decline in nitrogen losses in erosion was also significant, from 20.4 lb/ac to 14.7 lb/ac, a 28% decrease.

Table 5.14 shows the simulated average annual nitrogen losses for each rotation year. In general the timing and relative magnitude of nitrogen losses do not change under nutrient management. Nitrogen losses in erosion and runoff closely correspond to the seasonal patterns of erosion and runoff. The timing of lateral and percolation losses of nitrogen is the same as before nutrient management, except for the fact that there are proportionately greater declines in losses when rye and barley are grown.

The concentration of organic nitrogen in the soil increases by less than half, from about 540 ppm to 800 ppm. The final concentration is 270 ppm less than the final concentration before nutrient management.

Phosphorus losses. When dairy manure is used under nutrient management, 36.6 lb/ac of phosphorus are applied annually on average, a decrease of 33%. The simulated annual average total phosphorus losses are 2.5 lb/ac, or 7% of the phosphorus applied. Nutrient management reduces phosphorus losses by 29%. Table 5.12 shows the simulate average annual phosphorus losses for each rotation year. Higher than average losses occur in the first five years, when corn is grown and before the alfalfa is established. After the alfalfa is established, losses drop significantly.

Losses of phosphorus in erosion constitute a greater share of total phosphorus losses after nutrient management. The concentration of labile phosphorus in the soil increased by about half, from 10.4 ppm to 15.7 ppm, over the 63-year simulation period. The final labile phosphorus concentration after nutrient management is about half the concentration at the end of the simulation before nutrient management.

After nutrient management, when hog manure is used, 90.8 lb/ac of phosphorus are applied on an average annual basis, a 50% decrease. The simulated average annual total phosphorus losses decrease by 43%, from 9.3 lb/ac to 5.3 lb/ac. Table 5.15 shows the average annual phosphorus losses for each rotation year. Losses are again higher when corn is grown and lower after the alfalfa is established. About 70% of the losses are in erosion; most of the remainder is in runoff.

The average annual phosphorus application when hog manure is used under nutrient management is still more than double the application when dairy manure is used under nutrient management. This is reflected, not only in higher losses, but in a greater buildup of labile phosphorus in the soil. The concentration of labile phosphorus in the soil increases in the course of the simulation from 12.6 ppm to 51 ppm, a three-fold increase. The concentration at the end of simulation is more than three times the final concentration when dairy manure is used under nutrient management. It is, however, less than half the buildup that occurs when hog manure is used without nutrient management.

Sensitivity of Nitrogen Losses to Manure Application Rate

A sensitivity analysis was performed to determine the effect of manure application rates on nitrogen losses. Figure 5.13 shows simulated average annual nitrogen losses as a function of dairy manure application rates, and Figure 5.14 shows losses as a function of hog manure application rates. In both sets of simulations, inorganic fertilizer was applied at the rates used before nutrient management.

Nitrogen losses increase linearly with application rate with both dairy manure and hog manure. With dairy manure, losses increase approximately 4.7 lb/t/ac. Considering that half the nitrogen applied as ammonium is lost through volatilization, two-thirds of the nitrogen added above the levels specified by nutrient management is lost, mostly in percolation. When hog manure is used, losses increase approximately 6.8 lb/t/ac. Again, approximately two-thirds of the additional nitrogen applied per ton than does not volatilize is lost in percolation, erosion, or runoff. Whether dairy manure or hog manure is used, there is little increase in yield with increasing application rates. Most of the nitrogen that is not lost is added to the soil.

Sensitivity of Nitrogen Losses to First Year Mineralization Rate

A sensitivity analysis was performed to determine if the fraction of available organic nitrogen applied as nitrate affects nitrogen losses. For conditions before and after nutrient management, using both dairy manure and hog manure, the scenarios were run at four different levels of nitrate application: (1) none of the available organic nitrogen applied as nitrate, (2) half of the available organic nitrogen applied as nitrate, (3) three-quarters of the available nitrogen applied as nitrate, (4) all of the available nitrogen applied as nitrate. The results are shown in Table 5.16 for dairy manure and Table 5.17 for hog manure.

Nitrogen reduction efficiency is sensitive to nitrate application rate for neither manure type. As the tables show, there is little variation in efficiency. As might be expected, as the nitrate application rate increases, more nitrogen is lost in runoff, lateral flow, and percolation, and less nitrogen is lost in erosion. Nevertheless, the proportion of losses in erosion, runoff, and subsurface flow does not change radically as the fraction of available organic nitrogen applied as nitrate changes. The bulk of the nitrogen losses occur in percolation, no matter what fraction of the nitrogen is applied as nitrate. For dairy manure, after nutrient management, there is a 48% increase in nitrogen losses in percolation and a 19% decrease in nitrogen losses in erosion as the fraction of nitrogen applied as nitrate increases from zero to 100%. For hog manure, percolation losses increase 22% and erosion losses decrease 13%.

Effect of Slope

A sensitivity analysis was performed to determine the effect of slope on nutrient losses and nutrient reduction efficiency. The scenario was simulated with a slope of 2% and 10%, before and after nutrient management, using both dairy manure and hog manure.

The overall effect of slope on hydrology was not changed by nutrient management or the type of manure used. Table 5.18 shows the average annual runoff, lateral flow, percolation, and erosion for the different slopes when dairy manure is used before nutrient management. The most significant effect of differences in slope is the change in erosion. Erosion increases with slope, more than doubling when the slope is increased from 2% to 5%, and more than doubling again when the slope increases from 5% to 10%. Over the ranges of slopes, the simulated average annual erosion ranges from 0.4 t/ac to 2.5 t/ac. Runoff and lateral flow also increase with increasing slope, but not as dramatically. Over the range of slopes, average annual runoff ranges from 4.4 in/ac to 5.8 in/ac, and lateral flow ranges from 0.3 in/ac to 1.4 in/ac. Average annual percolation decreases from 13.2 in/ac to 10.0 in/ac.

Table 5.19 shows average annual nitrogen losses and nitrogen reduction efficiency as a function of slope when dairy manure is used, and Table 5.20 shows average annual phosphorus losses as a function of slope for dairy manure. Tables 5.21 and 5.22 show the same quantities for hog manure. The increase in erosion with increasing slope increases both nitrogen and phosphorus losses in erosion proportionally in all simulations. Since phosphorus losses are dominated by erosion, this leads to a substantial increase in total phosphorus losses for all simulations. Three times as much phosphorus is lost, both before and after nutrient management, when the slope is 10% than when it is 2%. Since losses are proportional to the concentration of phosphorus in the soil, and nutrient management is effective in reducing soil phosphorus concentrations, phosphorus reduction efficiency does not vary as much. It ranges from 27% to 29% for dairy manure and 43% to 45% for hog manure.

Losses of nitrogen in erosion more than triple for all simulations as the slope is increased for 2% to 10%, but since erosion losses are a less significant fraction of total nitrogen losses, total nitrogen losses do not vary as much with slope as total phosphorus losses. Simulated total average annual nitrogen losses increase by no more than 27% as the slope increases from 2% to 10%. Increases in losses in erosion and runoff are offset by decreases in losses in percolation. Nitrogen reduction efficiency varies even less with slope, ranging from 40% to 44% for dairy manure and 59% to 63% for hog manure.

Effect of Soil Type

The effect of soil type on nutrient losses and nutrient reduction efficiency was examined by performing simulations on two additional soils: a Berks shaly silt loam and a Dekalb channery sandy loam. Both soils, like the Calvin soil used in scenarios, belong to Hydrologic Group C. The slopes of these soils, like the Calvin soil, are in the 3-8 % range, and were modeled at 5%.

Hydrology and erosion. Table 5.23 shows the simulated average annual runoff, lateral flow, percolation and erosion for the two new soils. Overall the soils are similar to each other, so the results are similar. Erosion on all three soils is minimal, averaging about a ton per year. The Dekalb soil is sandier than the other two soils, which results in about a quarter more percolation per year on average than the Berks or Calvin soils.

Nitrogen losses and nitrogen reduction efficiency. Table 5.24 shows the nitrogen losses and the nitrogen reduction efficiency for the simulations on the Berks and Dekalb soils. Given the overall similarity of the soils, it is not surprising that the simulated average annual nitrogen losses are similar overall. There are no significant differences in nitrogen losses between the Berks and Calvin soils. The Dekalb soil tends to have greater percolation losses, but the nitrogen reduction efficiency on the Dekalb soil, when either hog or dairy manure is used, is within two percent of the other soils. The reduction in the rate of nitrogen application on the Dekalb soil led to a reduction in nitrogen losses similar to that which occurred on the Berks and Calvin soils.

Phosphorus losses and phosphorus reduction efficiency. Table 5.25 shows the simulated average annual phosphorus losses and phosphorus reduction efficiency for the simulations on the Berks soil and the Dekalb soil. Overall phosphorus losses are small. The Dekalb soil has slightly less erosion than the Berks soil or Calvin soil, so phosphorus losses in erosion and overall are less. The phosphorus reduction efficiency of the Berks soil is about the same as the other two soils, because phosphorus losses in erosion is dependent of soil phosphorus concentration, and the difference in concentration before and after nutrient management is roughly proportional to the reduction in applied phosphorus.

Chapter Six

Second Pennsylvania Scenario: Dairy Operation in Piedmont Region

Scenario Description

The second Pennsylvania scenario represents an eight-year rotation of corn and alfalfa on a dairy farm in Lancaster County in the Piedmont Region. Actually, two different scenarios are represented, one in which the corn is grown for grain and one in which the corn is grown for silage. They differ in planting and harvesting dates, and the rate and timing of fertilizer application.

Table 6.1 shows the schedule of farm operations for the rotation with corn silage before nutrient management. Corn is grown in the first four years. Alfalfa is planted in the fifth year and cut in the last three years. The corn is planted in April and harvested in September. The alfalfa is planted in August. It is cut in May, June, August and September.

Two manure applications are made to the corn each year, 35 t/ac in November and 28 t/ac in April before planting. The April application is incorporated. In the first year, 35 t/ac of manure are applied in January, instead of the previous November. Seventy pound/acre of inorganic nitrogen is applied as starter fertilizer to the corn. No fertilizer is applied to the alfalfa.

Table 6.6 shows the farming operations for the corn silage rotation after nutrient management. Under nutrient management, only one manure application is made to the corn, just before planting, at a rate of 24 t/ac. The nitrogen applied as starter fertilizer is reduced, and phosphorus is added. Phosphorus is applied before the alfalfa is planted, and both nitrogen and phosphorus inorganic fertilizer is applied to the alfalfa in August of the sixth, seventh, and eighth years. A manure application is made in November before the first year of corn is planted.

Table 6.10 shows the schedule of farming operations when grain corn is grown before nutrient management. Generally, the corn is planted in May and harvested in October although in the first year the operations occur later in year. Two manure application are made, one in January and one in May. Inorganic nitrogen is also used as starter fertilizer. No manure or fertilizer is applied to the alfalfa until manure is applied in the November before corn is planted.

Table 6.15 shows the schedule of farming operations for the grain corn rotation after nutrient management. Only one manure application is made to the corn, just before planting, at a reduced rate. The rate of application of the nitrogen starter fertilizer is also reduced. Phosphorus is applied before planting the alfalfa, and both nitrogen and phosphorus is applied in August in the sixth, seventh, and eighth years of the rotation. There is no manure application the November before corn is planted. Instead, the manure is applied in the March before the corn is planted.

The soil represented is a Hagerstown silt loam, with a 3-8% slope. The slope was set at 5% for all simulations. The Hagerstown soil belongs to Hydrologic Group B. The simulation period was 64 years, or eight eight-year rotation periods.

Hydrology and Erosion

Overall, the two rotations have similar hydrology, although there is less erosion in the grain corn rotation. Table 6.2 shows the simulated average annual precipitation, runoff, lateral flow, percolation, and evapotranspiration for the corn silage rotation before nutrient management. The standard deviation, maximum, and minimum values of these quantities are also shown. Table 6.11 shows these same statistics for the grain corn rotation. Tables 6.3 and 6.12 shows the average annual runoff, lateral flow, percolation, and erosion for each rotation year for the corn silage and grain corn rotations, respectively. Nutrient management does not have a great effect on the hydrology and erosion of the simulations, so for the most part, the hydrology and erosion after nutrient management will not be discussed.

The water budget. The same weather data that was used in the first Pennsylvania scenario was also used in the second scenario. See the above discussion for details. Of course, the simulated precipitation is the same, averaging 39.2 in/ac annually.

In the corn silage rotation, simulated evapotranspiration accounts for 25.3 inches, or 65%, of annual precipitation on average. Percolation accounts for the 8.8 inches, or 22%, of precipitation annually on average. Runoff accounts for 4.4 inches, or 11%, and lateral flow only 0.7 inch. There is a lot of variability in runoff and percolation. Annual runoff ranges from 0.1 in/ac to 12.9 in/ac, and annual percolation ranges from 0.7 in/ac to 21.7 in/ac. Figure 6.1 shows the simulated average monthly runoff during the rotation. There is significantly more runoff in the years when corn is planted than when alfalfa is planted. Figure 6.2 shows the simulated average monthly percolation through the rotation. Percolation tends to higher in winter and early spring. It tends to be higher also when alfalfa is growing. Under nutrient management, there is a slight increase in runoff and a slight decrease in percolation. The increase in runoff occurs particularly in the seventh year of the rotation, and is due to a decrease in simulated alfalfa cover. The decrease in percolation for the most part is derived from the increase in runoff.

In the grain corn rotation, simulated evapotranspiration account for 25.1 inches, or 64% of annual precipitation. Percolation accounts for 9.0 inches or 23% of annual precipitation, while runoff accounts for 4.3 inches or 11% of rainfall. Thus, on an average annual basis, the water budgets of the two rotations are almost identical. The simulated hydrology for grain corn rotation follows the same pattern as that for the corn silage rotation through the rotation period, with higher runoff in the years when corn is grown and higher percolation when alfalfa is grown.

Erosion. Simulated average annual erosion for the silage corn rotation is 4 t/ac, ranging from 0.1 t/ac to 23.4 t/ac. As might be expected, more erosion occurs when corn is grown than when alfalfa is grown. Simulated erosion during the corn years of the rotation cycle is about ten times higher than during the alfalfa years of the cycle. Figure 6.3 shows simulated average monthly erosion through the rotation cycle. Erosion tends to be higher in the summer months because of rainfall intensity and a decrease in crop residue on the soil surface.

The simulated erosion for the grain corn rotation is significantly less than the erosion for the silage corn rotation. Average annual erosion is 2.4 t/ac, 40% less than for the silage corn rotation. It ranges from 0.1 t/ac to 16.9 t/ac per year. Figure 6.4 shows the simulated average monthly erosion through the rotation. Erosion is less than that for the silage rotation in each of the years in which corn is grown, and it is noticeably less in the first year. This is due partially to the change in schedule and partially to chance. In the corn grain rotation, the corn is harvested later, so there is more crop cover in September, which by chance, is where the most erosive storms took place in the first year rotation. In general, however, crop cover late in the growing season seems to suppress the potential for erosion in the corn grain scenario. Greater crop residue year-round in the corn grain scenario also helps to limit erosion.

Nutrient Losses

Nitrogen losses in the corn silage rotation before nutrient management. Figure 6.5 shows the major components of the nitrogen budget. Before nutrient management, 402.5 lb/ac of nitrogen are applied as fertilizer on an average annual basis, 94.3 lb/ac are in ammonium form, of which 49.3 lb/ac, or more than half, volatilize.

The simulated average annual nitrogen content is 209.3 lb/ac in silage corn, and 248.3 lb/ac in alfalfa. That means on average crop uptake accounts for 197.8 lb/ac of nitrogen on an annual basis. Yields are high. Using the data supplied by Meisinger and Randall, silage corn yield is approximately 29 t/ac and alfalfa over 5 t/ac as hay. Nitrogen fixation accounts for 83.8 lb/ac on average annually. Crop yield accounts for 45% of annual nitrogen inputs after volatilization.

Table 6.4 shows simulated average annual nitrogen losses by rotation year. The total simulated average annual nitrogen losses is 179.2 lb/ac, or 41% of annual nitrogen inputs after volatilization. The simulated average annual nitrogen losses in percolation are 89.3 lb/ac. Annual losses range from 7.1 lb/ac to 366.8 lb/ac. Nitrogen losses in lateral flow account for another 5.7 lb/ac per year. Figure 6.6 shows the average monthly nitrogen losses in percolation and lateral flow. Nitrogen losses in percolation follow the seasonal trends in percolation, and in general, more losses occur in rotation years with higher percolation, although Year 7, with the highest percolation on average, does not have the highest percolation losses. The highest losses occur in

Years 5 and 6, after the corn is harvested and before the first cutting of alfalfa.

The average annual nitrogen losses in erosion are 68.1 lb/ac. Annual losses range from 1.7 lb/ac to 350.6 lb/ac. Figure 6.7 shows the average monthly nitrogen losses in erosion during the rotation. It closely follows the seasonal pattern of erosion, so that more nitrogen is lost in the years in which corn is grown than in the years in which alfalfa is grown, and more losses occur in summer than in winter. There is a buildup of the concentration of organic nitrogen in the soil profile over the course of the simulation. The concentration rose about 240 ppm, from 460 ppm to 700 ppm, an increase of a little more than 50%.

Simulated nitrogen losses in runoff amount to 16.2 lb/ac on an average annual basis. Annual losses range from no losses to 53.5 lb/ac. Figure 6.8 shows the average monthly nitrogen losses in runoff through the rotation year. While higher losses occur only when runoff is higher than average, it is not always the case that higher runoff results in higher nitrogen losses. In particular, there is little nitrogen lost in runoff after the alfalfa is established.

Nitrogen losses in the grain corn rotation before nutrient management. Figure 6.9 shows the major components of the average annual nitrogen budget for the grain corn rotation before nutrient management. On average, 275 lb/ac of nitrogen are applied in fertilizer annually. 58.4 lb/ac are in the form of ammonium, and volatilization losses are 29.4 lb/ac. Averaged over the whole rotation cycle, 88.6 lb/ac of nitrogen is fixed each year annually, so total nitrogen inputs after volatilization amount to 334.2 lb/ac annually.

The average annual nitrogen content in corn yield is 130.6 lb/ac and the average annual nitrogen content in alfalfa is 205.7 lb/ac, so averaged over the whole rotation cycle, crop yield accounts for 142.4 lb/ac on average annually of the nitrogen budget, or 43% of nitrogen inputs. Using the data of Meisinger and Randall, corn yield is approximately 179 bu/ac, which is perhaps an unrealistically high yield. The simulated average yield of alfalfa hay is approximately 4.8 t/ac.

Table 6.13 shows the simulated average annual nitrogen losses by rotation year. The total simulated average annual nitrogen losses are 141.1 lb/ac, or 42% of annual nitrogen inputs after volatilization. In this simulation, nitrogen losses in percolation are again the largest source of environmental losses. On average, 88.6 lb/ac are lost each year. Annual losses range from 5.4 lb/ac to 365.9 lb/ac. Nitrogen losses in lateral flow account for another 5.4 lb/ac annually. Losses generally follow the same seasonal pattern as in the corn silage rotation scenario, but vary in magnitude more widely. Figure 6.10 shows the average monthly nitrogen losses in percolation and lateral flow through the rotation period.

The simulated average annual nitrogen losses in erosion are 32.7 lb/ac, ranging from 1.2 lb/ac to 206.1 lb/ac. Nitrogen losses in erosion follow closely the seasonal trends in erosion. With the exception of Year 1, more losses occur in the years in which corn is grown, and these losses tend to occur in the summer when the intensity of rainfall is highest. Over the course of the simulation, the concentration of organic nitrogen in the soil rose about 235 ppm, from 430 ppm to about 465 ppm.

The simulated average annual nitrogen losses in runoff are 14.5 lb/ac, ranging annually from no losses to 51.8 lb/ac. Runoff losses tend to be higher in those years when corn is grown and before the alfalfa is established.

Nitrogen losses in the corn silage rotation after nutrient management. Figure 6.11 shows the major components of the average annual nitrogen budget for the corn silage rotation after nutrient management. After nutrient management, only 142.9 lb/ac of nitrogen are applied in fertilizer on an average annual basis, a decrease of 64%. 30.4 lb/ac of the nitrogen are in the form of ammonium, and 14.5 lb/ac of it volatilize annually on average. Simulated average annual nitrogen fixation drops 22%, to 65.7 lb/ac. Annual total nitrogen inputs after volatilization are thus 194.1 lb/ac, a decrease of 56%.

Simulated crop yields also decrease. The nitrogen content of the average annual corn yield is

150.9 lb/ac, and the nitrogen content of alfalfa is 194.4 lb/ac, giving an average annual nitrogen content in crop yield of 148.4 lb/ac, or about three-quarters of the annual nitrogen input. Despite the increase, crop yields are still relatively high. Using the data from Meisinger and Randall, average annual corn silage yield is about 21 t/ac and alfalfa yield is about 4.5 t/ac.

Environmental nitrogen losses drop dramatically, especially nitrogen losses in percolation. Table 6.8 shows the simulated average annual nitrogen losses by rotation year. Total average annual nitrogen losses are 44.3 lb/ac, a decrease of 75% from the losses before nutrient management. Average annual nitrogen losses in percolation have decreased 93%, to 6.1 lb/ac. Annual losses range from no losses to 24.1 lb/ac. Only in Year 6 is the annual average above 10 lb/ac. Losses in lateral flow also decrease to 1.6 lb/ac annually. Runoff losses also decrease by almost two-thirds. The simulated average annual nitrogen losses in runoff are 6.5 lb/ac, ranging annually from no losses to 23.2 lb/ac.

Simulated nitrogen losses in erosion decreased less dramatically than losses in percolation, but still dropped by more than half, to 30.1 lb/ac. The drop in erosion losses is roughly proportional to the decrease in nitrogen inputs. Losses of nitrogen in erosion constitute more than two-thirds of the environmental losses after nutrient management. Annual losses range from 0.5 lb/ac to 165.1 lb/ac, and follow the same seasonal trends as before nutrient management. The increase in soil nitrogen concentration is less than 10%.

Nitrogen losses in the grain corn rotation after nutrient management. Figure 6.12 shows the major components of the average annual nitrogen budget for the grain corn rotation after nutrient management. After nutrient management, the average annual nitrogen content of fertilizer and manure is 154 lb/ac, a decrease of 44%. 28.86 lb/ac of the nitrogen are applied as ammonium, of which 12.7 lb/ac volatilize on average annually. Average annual nitrogen fixation increases by about 10% to 97.2 lb/ac. Average annual nitrogen inputs after volatilization are thus 238.5 lb/ac, a decrease of 29%.

Simulated corn yields decreased slightly. The average annual nitrogen content in corn yield decreased by less than 3%, to 127.2 lb/ac. On the other hand, alfalfa yields increased. The average annual nitrogen content in the alfalfa yield increased by 20% to 247.8 lb/ac, representing, according to the data supplied by Meisinger and Randall, a yield of over 5 t/ac. Averaged over the whole rotation, the average annual nitrogen content in crop yield was 156.5 lb/ac, or 66% of annual nitrogen inputs.

Total simulated environmental nitrogen losses decreased by over 50%, to 65.5 lb/ac on average annually. Table 6.17 shows the average annual nitrogen losses by rotation year. The greatest decrease in losses occurred in percolation. Simulated average annual nitrogen losses in percolation decreased by 69%, to 27.4 lb/ac. Annual losses ranged from no losses to 139.2 lb/ac, and generally follow the same seasonal trends and timing as before nutrient management. Nitrogen losses in lateral flow also decreased by over 50%, to 2.5 lb/ac annually. Average annual nitrogen losses in runoff dropped 39%, to 8.8 lb/ac.

Nitrogen losses in erosion, however, only dropped 18%. Simulated average annual nitrogen losses in erosion were 26.7 lb/ac, ranging annually from 1.0 lb/ac to 157.9 lb/ac. The concentration of organic nitrogen in the soil increased by about 100 ppm over the course of the simulation, from 440 ppm to 535 ppm.

Phosphorus losses. In all four Piedmont simulations on a Hagerstown soil, the bulk of phosphorus losses occur in erosion, and follow the timing of erosion losses for that scenario.

Table 6.5 shows the average annual phosphorus losses by rotation year for the corn silage scenario before nutrient management. On average, 64.1 lb/ac of phosphorus is applied in manure and fertilizer annually. Simulated average annual phosphorus losses are 10.8 lb/ac, or 17 % of the applied phosphorus. 9.8 lb/ac, or over 90%, are lost in erosion. The concentration of labile phosphorus rose from 11 ppm to 23 ppm over the course of the simulation.

After nutrient management, only 30.4 lb/ac of phosphorus are applied on average annually, a reduction of over 50%. Table 6.9 shows the average annual phosphorus losses by rotation year. Simulated average annual phosphorus losses decreased to 6.3 lb/ac, a drop of 42%. Losses account for 21% of applied phosphorus annually. On average 6.0 lb/ac, or over 95%, were lost in erosion. The concentration of labile phosphorus in the soil profile increased over the course of the simulation from 7 ppm to 12 ppm.

Table 6.14 shows the average annual phosphorus losses by rotation year for the grain corn rotation before nutrient management. On average, 41.0 lb/ac of phosphorus are applied in manure and fertilizer annually. Simulated average annual phosphorus losses are 5.4 lb/ac, or 13% of the applied phosphorus. 4.8 lb/ac, or about 90%, are lost in erosion. The concentration of labile phosphorus rose from 8 ppm to 15.5 ppm over the course of the simulation.

After nutrient management, only 26.5 lb/ac of phosphorus are applied on average annual basis, a reduction of 35%. Table 6.18 shows the average annual phosphorus losses for each rotation year. Simulated average annual phosphorus losses decreased to 2.6 lb/ac, a drop of 52%. Losses account for about 10% of applied phosphorus annually. On average 2.5 lb/ac, or over 95%, were lost in erosion. The concentration of labile phosphorus in the soil profile actually decreased slightly over the course of the simulation.

Sensitivity of Nitrogen Losses to Manure Application Rate

A sensitivity analysis was performed to determine the effect of manure application rates on nitrogen losses. Figure 6.13 shows simulated average annual nitrogen losses as a function of dairy manure application rates for the corn silage rotation, and Figure 6.14 shows losses for the grain corn rotation. In both figures, the bar marked "MN" shows losses under nutrient management. For other simulations, all manure applications in the scenarios before nutrient management were made at the specified rate, even though in the original scenarios, before nutrient management, manure was applied at different rates at different times of year. Inorganic fertilizer applications were made at the rate and timing of the corresponding scenario before nutrient management.

As the figure shows, losses increase linearly as a function of manure application rates. For the silage corn rotation, the rate of increase is approximately 6.8 lb additional nitrogen lost per ton of additional manure. The rate for the grain corn rotation is 5.6 lb/t. Nitrogen losses in percolation increase disproportionately with increasing application rates in both scenarios. That is, as the manure application rate increase, an increasing proportion of losses occur in percolation.

Assuming that half of the nitrogen applied as ammonium volatilizes, each ton of dairy manure contains 8.7 lb of nitrogen. Thus nearly 80% of the nitrogen applied in the higher manure application rates is lost in the corn silage rotation, and approximately 65% of the additional nitrogen applied is lost in the grain corn rotation. The rate at which losses increase with increasing application rates is less in the grain corn rotation, because losses in erosion are less. The additional nitrogen applied in manure in this case contributes to the buildup of soil nitrogen.

Sensitivity of Nitrogen Losses to First Year Mineralization Rate

A sensitivity analysis was performed to determine if the fraction of available organic nitrogen applied as nitrate affects nitrogen losses. The silage corn rotation and the corn grain rotation were simulated, both before and after nutrient management, at four different levels of nitrate application: (1) none of the available organic nitrogen applied as nitrate, (2) half of the available organic nitrogen applied as nitrate, (3) three-quarters of the available nitrogen applied as nitrate, (4) all of the available nitrogen applied as nitrate. The results are shown in Table 6.19 for corn silage and Table 6.20 for grain corn.

Simulation results did not vary greatly for either rotation when the fraction of available organic nitrogen applied as nitrate is changed. As can be expected, as the fraction applied as nitrate increases, less nitrogen is lost in erosion and more nitrogen is lost in runoff, lateral flow, and percolation. Total losses generally increased with increasing nitrate applications, except for the corn silage rotation under nutrient management, where the increase in percolation losses was less than the decrease in erosion losses. Total losses varied with changes in nitrate application by no more than 16%. Nitrogen reduction efficiency varied even less: the range of values varied by less than 10%, ranging from 72% to 78% for the corn silage rotation and 53% to 54% for the grain corn rotation.

Effect of Slope

A sensitivity analysis was performed to determine the effect of slope on nutrient losses and nutrient reduction efficiency. Both the corn silage rotation and the grain corn rotation, before and after nutrient management, were simulated with slopes of 2% and 10%.

The overall effect of slope on hydrology was not changed by nutrient management. Table 6. 21 shows the average annual runoff, lateral flow, percolation, and erosion for corn silage rotation with different slopes. Table 6.24 shows the same quantities for the grain corn rotation. In both rotations, the effect of slope on hydrology is disproportionately less than the change in slope. When the slope increase four-fold, from 2% to 10%, percolation decreases in both rotations about 25%, and runoff increases by about a third. The effect of slope on erosion is more significant. The increase in erosion is proportionally greater than the increase in slope. At a 5% slope, erosion was greater for the corn silage rotation than the grain corn rotation. The difference widens at a 10% slope, where the simulated average annual erosion in the silage corn rotation is 10.3 t/ac, while the erosion in the grain corn rotation is 5.9 t/ac.

Table 6.22 shows the simulated average annual nitrogen losses, both before and after nutrient management, for the silage corn rotation with different slopes. Table 6.25 shows the same quantities for the grain corn rotation. The nitrogen reduction efficiencies are also shown in the same tables. Total nitrogen losses increase with increasing slope. Average annual losses of nitrogen in erosion vary proportionately with slope. Losses of nitrogen in runoff also increase, but do not double when the slope is increased from 2% to 10%. Losses in lateral flow also becomes more significant as the slope increases. These trends are somewhat balanced by a decrease in nitrogen losses in percolation with increasing slope. Except in the case of the grain corn rotation before nutrient management, percolation losses decrease by half as the slope increases from 2% to 10%. Nitrogen reduction efficiency also decreases with slope. As the slope varies from 2% to

10%, the nitrogen reduction decreases from 82% to 66% in the silage corn rotation and from 59% to 47% in the grain corn rotation.

Table 6.23 shows the simulated average annual phosphorus losses, both before and after nutrient management, for the silage corn rotation with different slopes. Table 6.26 shows the same quantities for the grain corn rotation. The phosphorus reduction efficiencies are also shown in the same tables. In all simulations, phosphorus losses remain dominated by losses in erosion. The variation in slope has little effect on losses in runoff or percolation. The simulated average annual phosphorus losses in erosion vary proportionally with slope. Phosphorus reduction efficiency decreases with increasing slope in the grain corn rotation. As the slope increases from 2% to 10%, efficiency drops from 58% to 50%. Efficiency increases in the silage corn rotation, however, from 40% to 45%, as the slope increases from 2% to 10%.

Effect of Soil Type

The effect of soil type on nutrient losses and nutrient reduction efficiency was examined by performing simulations on two additional soils: a Manor silt loam, 3-8 % slope, and a Conestoga silt loam, 3-8% slope. These soils are similar to the Hagerstown silt loam, the original soil used in the Piedmont simulations. Besides having their surface texture and slope in common, all three belong to Hydrologic Group B.

It is not surprising, then, that the results of the simulations using the Manor soil and the Conestoga soil are similar to the original simulations. Table 6.27 shows the simulated average annual runoff, lateral flow, percolation, and erosion for the silage corn rotation before nutrient management for the three soils. Table 6.30 shows the same statistics for the grain corn rotation. The Manor soil tends to have less runoff and more percolation that the other two soils. In the corn silage rotation erosion on the Manor and the Conestoga soils is more than 10% greater than the erosion on the Hagerstown soil. The increase is not as great in the corn grain rotation, where erosion is less because of increased crop residue and the timing of the corn harvest.

The nutrient reduction efficiencies tend to be slightly higher on the Conestoga soil and slightly lower on the Manor soil, compared to the Hagerstown soil, but the differences are small. Tables 6.28 and 6.31 show the average annual nitrogen losses and nitrogen reduction efficiencies for simulations using the corn silage rotation, and the grain corn rotation, respectively, on the different soils. Tables 6.29 and 6.32 the same statistics for phosphorus. Most of the efficiencies differ by no more than a few percent from one another. The Manor soil simulations and the Conestoga soil simulations tended to have higher nitrogen losses in percolation and lower losses in erosion and runoff than the Hagerstown soil. Even when the differences are large relative to the quantities involved, however, they do not affect the efficiency of nutrient management. The simulated average annual nitrogen loss in percolation for the corn silage rotation after nutrient management was almost twice as high for the Manor soil as for the Hagerstown soil, but percolation losses in this scenario are small compared to erosion losses, and thus the difference does not affect total nitrogen losses greatly. The largest difference in phosphorus reduction efficiency, more than 6%, is between the Conestoga soil and the other soils for the grain corn rotation, but it is due to a relatively small difference, 0.5 lb/ac, in average annual phosphorus losses.

Chapter Seven

First Maryland Scenario: Poultry Operation in the Coastal Plain

Scenario Description

The first Maryland scenario represents a two-year crop rotation on a poultry farm in Caroline County on the Eastern Shore. The first year of the rotation is corn double-cropped with wheat or another small grain, and the second year is no-till soybeans. Both broiler litter and inorganic fertilizer is used in the rotation. The soil simulated in this scenario is a Sassafras sandy loam, 0-2% slope. In the simulations, the slope was set at 1%. The soil belongs to Hydrologic Group B. The simulation period was set at 40 years.

Table 7.1 shows the schedule of farming operation for the two year rotation before nutrient management. Grain corn is planted at the end of April and harvested at the beginning of October. Wheat or barley is planted in October and harvested the next June. The soybeans are planted immediately after harvesting the wheat and are themselves harvested in November.

Before nutrient management, 3 t/ac of broiler litter are applied at the beginning of February before the corn is planted. Inorganic nitrogen and phosphorus is applied to the corn at planting. Two months after planting, in the middle of June, the corn is sidedressed with inorganic nitrogen fertilizer. The wheat is fertilized at planting with both inorganic nitrogen and phosphorus. Inorganic nitrogen fertilizer is also applied to the wheat in both February and March. No fertilizer or litter is applied to the soybeans.

The only tillage operations occur between harvesting the corn and planting the wheat. After the corn is harvested, the soil is tilled with a moldboard plow. The fertilizer applied before planting the wheat is incorporated with a disk or harrow. Both the corn and the soybeans are grown in the residue of the previous crop.

After nutrient management, the timing, but not the rate, of the manure application is changed, from February 1 to March 1. In addition, the nitrogen sidedress fertilizer application is applied on the basis of a pre-sidedress soil nitrate test (PSNT). The PSNT measures the concentration of nitrate in the first foot of soil. If the concentration is greater than 21 ppm, it implies that more than 100 lb/ac of nitrate are available in the soil, and the sidedress fertilizer application is unnecessary. If it is less than 21 ppm, the sidedress application is made. For this rotation, the sidedress fertilizer is only necessary once or twice every ten years (P. Steinhilber, H. Callahan, personal communication).

The EPIC software was modified to simulate a PSNT and to make the sidedress fertilization dependent on the results of the PSNT. Examination of the modeling results showed that there usually was adequate nitrate in the root zone soil, but not necessary in the first foot. Instead of calculating the concentration of nitrate in the soil, the simulated test checks whether there is 100 lb/ac of nitrate in the first three feet of soil. If there is, the sidedress fertilizer is not applied.

Hydrology and Erosion

Weather data. Data from the Cambridge Water Treatment Plant for the period 1949-1992 was used for daily maximum and minimum temperature, and daily precipitation. Other weather data was generated synthetically in EPIC using parameters for Baltimore, MD. The same weather data was used for all the Maryland scenarios. The average annual precipitation was 44.4 in/ac, ranging from 31.7 to 63.8 in/ac annually. Figure 7.1 shows the average monthly precipitation. Precipitation is fairly evenly distributed throughout the year, except perhaps for the months of July and August, which tend to get almost and inch more precipitation than the other months.

The water budget. Table 7.2 shows the simulated average annual precipitation, runoff, lateral flow, percolation, and evapotranspiration, as well as the standard deviations and range of annual values of these quantities, for the scenario before nutrient management. Table 7.3 shows the average annual runoff, lateral flow, and percolation by rotation year. Nutrient management does not effect hydrology or erosion, so only the scenario before nutrient management will be discussed.

Of the 44.4 in/ac of annual precipitation, almost 60%, or 26.5 inches, is accounted for by evapotranspiration. Simulated average annual percolation accounts for 13.4 inches, or 30%, of the annual water budget, ranging from 3.8 in/ac to 24.1 in/ac. Lateral flow is minimal. Simulated annual runoff is 4.2 in/ac, or less than 10% of annual precipitation. Runoff ranges from 0.6 to 13.3 in/ac annually.

Considerably more runoff occurs in the first year of the rotation than the second year. Figure 7.2 shows average monthly runoff during the rotation. The presence of winter wheat suppresses runoff . More percolation also occurs in the first year of the rotation. Figure 7.3 shows the average monthly percolation during the rotation. Percolation is generally low in the summer and higher in the winter. It highest in the winter between the first and second years of the rotation.

Erosion. The simulated average annual erosion is 0.7 t/ac, ranging from 0.1 t/ac to 3.1 t/ac. As Table 7.3 shows, erosion is higher in the first year of the rotation than the second year. Figure 7.4 shows the average monthly erosion over the rotation cycle . In both years erosion tends to be highest in late summer, because of rainfall intensity and the decay of crop residues that had been protecting the soil. The months of July, August, and September in Year 1 account for about half of the erosion in the rotation cycle.

Nutrient Losses

The nitrogen budget before nutrient management. Table 7.2 shows the simulated average annual nitrogen losses and annual nitrogen content in crop yields. Table 7.4 shows average annual nitrogen losses by rotation year. Figure 7.5 shows the major components of the average nitrogen budget.

On an average annual basis, 177.5 lb/ac of nitrogen are applied in manure and fertilizer, 22.5 lb/ac of which are in the form of ammonium. Over three-quarters of the nitrogen in ammonium form, or

17.7 lb/ac annually, volatilizes. This is not surprising since the broiler litter is left unincorporated on the soil surface after it is applied. Nitrogen fixation adds 100.7 lb/ac annually when average over the rotation cycle, so total average annual nitrogen inputs after volatilization amount to 260.5 lb/ac.

The simulated average annual nitrogen content of the crop yield is 170.4 lb/ac, or over 65% of annual nitrogen inputs. The average annual nitrogen content of corn, wheat, and soybean yields is 113.3, 94.1, and 133.4 lb/ac, respectively, which translates into average annual yields of 155, 95, and 40 bu/ac, respectively, using the data of Meisinger and Randall. The corn grain yield is larger than the targeted yield of 125 bu/ac.

Total average annual nitrogen losses were 43.8 lb/ac, or about 25% of average annual nitrogen applied in fertilizer and manure and 17% of average annual nitrogen inputs. On average, losses were higher in the first year of the rotation than in the second. Over two-thirds of the losses were in percolation, 16% of the losses were in runoff, and 15% of the losses were in erosion. Losses in subsurface flow were negligible.

Figure 7.6 shows the average monthly nitrogen losses in lateral flow and percolation. Losses are highest in the winter between the first and second years of the rotation, and are considerably lower over the rest of the rotation cycle. The winter between the second and first year, when soybeans goes into corn, has relatively low losses, despite the fact that percolation is also high then. The nitrogen fixation rate indicates the soybeans have already taken up all available nitrate in the root zone, so there is little left to leach out of the soil the winter after the soybean harvest.

Figure 7.7 shows the average monthly nitrogen losses in runoff over the rotation cycle. Losses are generally low except for the month of February in the first year of the rotation, when the broiler litter is applied. Almost half of the nitrogen lost in runoff occurs in the month after the litter is applied.

Figure 7.8 shows the average monthly nitrogen losses in erosion. The timing and magnitude of nitrogen losses in erosion mirror erosion losses. More nitrogen is lost in erosion during the first year of the rotation, especially in late summer.

The concentration of organic nitrogen in the top three feet of soil increases by about a third over the course of the forty-year simulation, from 300 ppm to 435 ppm.

The nitrogen budget after nutrient management. Table 7.6 shows the simulated average annual nitrogen losses and annual nitrogen content in crop yields. Table 7.7 shows average annual nitrogen losses by rotation year. Figure 7.9 shows the major components of the average nitrogen budget.

The rate of litter application does not change after nutrient management. Sidedress nitrogen, however, is only applied to corn if the PSNT calls for it. In the forty-year simulation, the test was performed 20 times, and six times the test did indicate that the sidedress fertilizer should be applied. This means that on average, 160.0 lb/ac of nitrogen was applied annually in fertilizer and litter. The amount applied in ammonium form does not change after nutrient management. Of the 22.5 lb/ac of nitrogen in ammonium applied annually, 17.7 lb/ac are lost in volatilization, the same amount lost before nutrient management. Although the timing of the litter application is changed, the litter is still surface applied, so high volatilization losses can be expected. The simulated average annual nitrogen content in crop yield is 169.9 lb/ac, practically unchanged from before nutrient management.

Total average annual nitrogen losses did decrease, however, by 33%. Total average annual losses were 29.5 lb/ac. Losses in percolation accounted for 60% of the losses. The simulated average annual losses in percolation were 17.7 lb/ac, ranging from no losses to 53.5 lb/ac. Annual nitrogen losses in erosion were 6.4 lb/ac on average, ranging from 0.5 lb/ac to 28.4lb/ac. The simulated average annual nitrogen loss in runoff was 5.1 lb/ac, ranging from no losses to 31.2 lb/ac annually. Losses of nitrogen in subsurface flow remained minimal.

Under nutrient management, the loss of nitrogen in percolation decreased by 40%. Figure 7.10 shows the average monthly nitrogen losses in lateral flow and percolation over the rotation cycle after nutrient management. The timing of the losses remains the same, but their magnitude has decreased.

Figure 7.11 shows the average monthly nitrogen losses in runoff over the rotation cycle after nutrient management. Although the highest losses in runoff still occur in the month when the broiler litter is applied, applying the litter in March rather than February has cut losses in the month after application by half.

Nitrogen losses in erosion are practically unchanged by nutrient management. Nutrient management also does not affect the buildup of nitrogen in the soil. The concentration of organic nitrogen in the top three feet of soil increased by about a third, from 300 ppm to 435 ppm.

Phosphorus Losses

Table 7.5 shows simulated average annual phosphorus losses by rotation year before nutrient management, and Table 7.8 shows average annual phosphorus losses after nutrient management.

Nutrient management does not change the quantity of phosphorus applied. 52.1 lb/ac are applied on an average annual basis. Both before and after nutrient management, total average annual phosphorus losses are 2.2 lb/ac, or about 4% of applied phosphorus. Before nutrient management, over 85% of the phosphorus is lost in erosion, most of that in the first year of the rotation. Phosphorus losses in runoff account for 14% of total losses. All of the losses occur in the first year of the rotation. Phosphorus losses in percolation were insignificant. After nutrient management, the distribution of losses was almost unchanged. Slightly less phosphorus was lost in runoff in the first year as a consequence of delaying the application of broiler litter a month. Over the course of the forty-year simulation period, the concentration of labile phosphorus in the soil in the top three feet increases from 9 ppm to 16 ppm in both simulations.

Effect of Poultry Litter Application Rate on Nitrogen Losses

A sensitivity analysis was performed to determine the effect of poultry litter application rates on nitrogen losses. Poultry litter was applied on March 1 at different rates, ranging from 3 to 9 t/ac. 50 lb/ac of nitrogen fertilizer were applied as sidedress to the corn every year.

Figure 7.12 shows simulated average annual nitrogen losses as a function of poultry litter application rates. The bar marked "NM" shows losses under nutrient management. As the figure shows, nitrogen losses increase linearly as a function of application rate. For every additional ton applied in the rotation cycle, 14.0 lb/ac of additional nitrogen is lost per year. Losses in runoff and erosion increase slightly as the rate is tripled, but most of the increase in losses is in percolation. If it is assumed that two-thirds of the nitrogen applied as ammonium volatilizes, for every additional ton of litter applied, 50 lb/ac of additional nitrogen is added, of which 28 lb/ac, or 56%, are lost, mostly in percolation. There is no increase in crop yield with increasing application rates. The nitrogen that isn't lost in runoff, erosion, or subsurface flow remains in the soil.

It should be noted that, before nutrient management, when 3 t/ac are applied March instead of February 1, total average annual nitrogen losses are 0.5 lb/ac less. Although there are 1.9 lb/ac less losses in runoff, percolation losses increase by about 1.4 lb/ac. Changing only the timing of the litter application thus decreases losses about 0.5 lb/ac per year.

Sensitivity of Nitrogen Losses to First-Year Mineralization Rate

A sensitivity analysis was performed to determine if the fraction of available organic nitrogen applied as nitrate affects nitrogen losses. The rotation was simulated, both before and after nutrient management, at four levels of nitrate application: (1) none of the available organic nitrogen applied as nitrate, (2) half of the available organic nitrogen applied as nitrate, (3) three-quarters of the available nitrogen applied as nitrate, and (4) all of the available organic nitrogen applied as nitrate. The results are shown in Table 7.9.

In general, as is the case in all the scenarios, as the fraction of organic nitrogen applied as nitrate increases, less nitrogen is lost in erosion, and more nitrogen is lost in runoff, lateral flow, and percolation. In general, total nitrogen losses increase with increasing nitrate applications. The simulation of the PSNT complicates the interpretation of the results, however, because the frequency of application of the sidedress fertilizer, and thus the amount of both nitrogen applied after nutrient management, varies with the amount of organic nitrogen applied as nitrate.

When no nitrate is applied, the PSNT calls for sidedress nitrogen to be applied sixteen out of the twenty years of corn in the simulation. When three-quarters of the available nitrogen is applied as nitrate, the PSNT induces sidedresssing four times, and when all of the nitrogen is applied as nitrate, the PSNT induces sidedressing only three times. The application of nitrate as sidedress fertilizer has a larger impact than the fraction of organic nitrogen in litter applied as nitrate. When all of the available nitrogen in litter is applied as nitrate, 22.5 lb/ac of nitrate are applied in the litter, less than half the amount of nitrate applied when the corn is sidedressed. More nitrate is thus applied on average when none of the available nitrogen is applied as nitrate than when all of the available nitrogen is applied as nitrate.

When sidedress nitrogen is applied, the difference between the simulation before and after nutrient management is only in the timing of the broiler litter application. As was explained in the previous section, changing the timing of the litter application reduces losses only by about 0.5 lb/ac per year. It is not surprising, then, that the nitrogen reduction efficiency drops to 9% when no available organic nitrogen is applied as nitrate, since the amount of nitrogen applied in the before and after nutrient management differs by only 5 lb/ac on an average annual basis. The additional nitrate sidedressed also explains the fact that percolation losses when no nitrogen is applied as nitrate are the largest among the simulation representing conditions after nutrient management, and that total losses for this simulation are the same as when all of the available organic nitrogen is applied as nitrate.

Since the organic nitrogen in poultry litter mineralizes rapidly, the simulation in which no organic nitrogen is applied as nitrate is probably less realistic than the simulations where some organic nitrogen is applied as nitrate. For rates of nitrate application above 50%, the nitrate content of the manure is larger on average than the nitrate sidedressed on the corn. The impact of the PSNT is therefore much less, and the variability in total nitrogen losses and nitrogen reduction efficiencies is lower. For the three scenarios in which some of the available nitrogen is applied as nitrate, total nitrogen losses differ by no more than 18%, and the range of efficiencies is less than 3%.

The Effect of Slope on Nutrient Losses and Nutrient Reduction Efficiency

A sensitivity analysis was performed to determine the effect of slope on nutrient losses and nutrient reduction efficiency. The rotation, both before and after nutrient management, was simulated at two additional slopes, 5% and 8%. Table 7.10 shows the average annual runoff, lateral flow, percolation, and erosion for the simulations with different slopes. Only the results before nutrient management are shown. Table 7.11 shows the impact of slope on nitrogen losses and nitrogen reduction efficiency, and Table 7.12 shows the impact on phosphorus losses and phosphorus reduction efficiency.

The most prominent effect of the change in slope is the increase in erosion and nutrient losses associated with erosion. The simulated average annual erosion is 0.7 t/ac with a 1% slope, 2.2 t/ac with a 5% slope, and 3.8 t/ac with an 8% slope. Nutrient losses increase proportionately. The simulated average annual nitrogen losses in erosion before nutrient management are 6.5 lb/ac at a 1% slope, 16.0 lb/ac at a 5% slope, and 26.1 lb/ac at an 8% slope. Since the amount of organic nitrogen applied does not change under nutrient management, the concentration of nitrogen in the soil does not change under nutrient management, and thus nutrient losses in erosion are not greatly effected by nutrient management. Runoff and nitrogen losses in runoff increase, while percolation and nitrogen percolation losses decrease, with increasing slope. Nitrogen losses in lateral flow also become more significant as slope increases. While nutrient management has an impact on nitrogen losses in runoff, lateral flow, and percolation, nitrogen losses in erosion make up a larger fraction of total losses as slope increases, so that the nitrogen reduction efficiency of nutrient management declines with increasing slope.

Because erosion increases with increasing slope, phosphorus losses also increase. Without nutrient management, phosphorus losses in erosion are 1.9 lb/ac at a 1% slope, 4.5 lb/ac at a 5% slope, and 7.1 lb/ac at a 8% slope. Total phosphorus losses are dominated by erosion at all slopes. Losses of phosphorus in runoff and percolation are unaffected by slope. As discussed earlier, nutrient management has almost no effect on phosphorus losses. The phosphorus reduction efficiency of nutrient management is practically zero at all slopes.

Chapter Eight

Second Maryland Scenario: Cash Grain Operation in the Coastal Plain

Scenario Description

The second Maryland scenario represents a four-year crop rotation on a cash grain farm. It is typical of such farms in Caroline County. It differs from the first Maryland scenario and all previous scenarios in that it uses no manure, only inorganic fertilizer. The soil is a Sassafras loamy sand, 0-2% slope, which was modeled at 1% slope. The soil belongs to Hydrologic Group B. Below the surface layer, it is almost identical to the Sassafras soil used in the first Maryland scenario. The simulation period was 40 years, or ten four-year rotation cycles.

Table 8.1 shows the schedule of farming operations for the four-year rotation. In the first year, corn is double-cropped with a small grain like wheat or barley. The corn is planted in April and harvested in September. The wheat is planted in October and harvested the following June. The corn is fertilized at planting with both nitrogen and phosphorus and also sidedressed with nitrogen one month after planting. The wheat is fertilized with both nitrogen and phosphorus at planting and also fertilized with nitrogen in February and March. Before the wheat is planted, the soil is plowed with a moldboard plow. The fertilizer applied when the wheat is planted is incorporated with a disk or harrow.

In the second year, after the wheat is harvested, soybeans are planted in June and harvested in November. No fertilizer is applied to the soybeans, and no tillage is used. In the third year, soybeans are double-cropped with wheat or another small grain. The soybeans are planted in May and harvested in October. They are fertilized with both nitrogen and phosphorus before planting. The soil is tilled with a chisel plow before fertilization and after harvest. The wheat is planted in October, and is fertilized and harvested on the same schedule as the first planting. In the fourth year, after the wheat is harvested in June, soybeans are planted for the third time, and harvested in November. No fertilizer is applied to the soybeans.

Hydrology and Erosion

Table 8.2 shows the simulated average annual runoff, lateral flow, percolation, and erosion, as well as the range of values of these quantities and their standard deviations.

The water budget. The same weather data for Cambridge, MD, and Baltimore that was used in the first Maryland scenario was also used in the second Maryland scenario. See the discussion above for details.

The simulated average annual precipitation is 44.4 in/ac. Annual evapotranspiration accounts for 26.1 inches or 59% of annual precipitation. Percolation on average accounts for 13.6 inches or 31% of the water budget, ranging from 3.7 in/ac to 24.4 in/ac annually. Lateral flow is minimal. Runoff accounts for 4.5 inches on average annually, or 10% of annual precipitation. Annual runoff ranges from 0.5 in/ac to 15.3 in/ac.

Table 8.3 shows the average annual runoff, lateral flow, percolation, and erosion by rotation year. Runoff is less than average in Years 2 and 4 when there is a winter wheat crop. Figure 8.1 shows the simulated average monthly runoff through the rotation cycle. There is not a clear pattern to the seasonal timing of runoff, though it appears that wheat or soybeans planted in wheat stubble lowers the general level of runoff.

Percolation is also lower on average in Years 2 and 4. Figure 8.2 shows the simulated average monthly percolation throughout the rotation cycle. Percolation tends to be higher in the winter and early spring in all rotation years. Percolation is also higher in those winter months in which wheat is grown, but by early spring, the presence of wheat raises transpiration and lowers the amount of water available for percolation in the rest of the year.

Erosion. Simulated average annual erosion is 0.6 t/ac, ranging from 0.1 t/ac to 2.4 t/ac. Erosion is lower in the second and forth years of the rotation. Figure 8.3 shows the average monthly erosion through the rotation cycle. Erosion tends to be higher in late summer. The presence of the small grain, both when it is grown and when it is left as no-till residue for the soybeans, tends to suppress erosion in the second and forth years of the rotation.

Nitrogen Budget

Table 8.2 shows average annual nitrogen losses and the nitrogen content in crop yield per harvest. Figure 8.4 shows the major components of the annual nitrogen budget. On an average annual basis, 85 lb/ac of nitrogen are applied in fertilizer. The average annual nitrogen content in crop yield is 174.0 lb/ac. The difference between the nitrogen in crop yield and fertilization is made up by nitrogen fixation, which averages 134.9 lb/ac per year over the whole rotation cycle.

The average annual nitrogen content in the corn, wheat, and soybean yields is 115.1,91.9, and 132.4 lb/ac, respectively. Using the data of Meisinger and Randall, this translates into an average annual yields of 158 bu/ac, 90 bu/ac, and 40 bu/ac, for corn, wheat, and soybeans, respectively.

Table 8.4 shows simulated average annual nitrogen losses by rotation year. Total annual average nitrogen losses are 25.2 lb/ac. Losses amount to 30% of nitrogen applied in fertilizer, but only 11% of annual nitrogen inputs, including both fertilizer and fixation. Over 70% of the nitrogen lost is in percolation. Simulated average annual nitrogen losses in percolation are 18.2 lb/ac, ranging from no losses to 65.1 lb/ac. More nitrogen is lost in percolation in the first and third years than in the second and fourth years. Losses in subsurface flow are minimal. Figure 8.5 shows the average monthly nitrogen losses in lateral flow and percolation. Losses are notably higher in the fall of the years in which winter wheat is grown.

Simulated average annual nitrogen losses in runoff are 4.1 lb/ac, ranging from no losses to 30.3 lb/ac annually. Figure 8.6 shows the average monthly nitrogen losses in runoff through the rotation year. Nitrogen losses in runoff are not correlated with the quantity of runoff. High losses occur February and March of the second year, when the wheat is fertilized, but do not occur under the same circumstances in the fourth year.

Simulated average annual nitrogen losses in erosion are 2.8 lb/ac, ranging from 0.3 lb/ac to 9.8 lb/ac annually. More nitrogen is lost in erosion in the first and third years of the rotation. Figure 8.7 shows the average monthly nitrogen losses in erosion throughout the rotation cycle. Nitrogen losses in erosion closely follow the seasonal pattern of erosion. More nitrogen is lost when erosion losses are greatest, in the summer of the first and third years.

Over the course of the 40-year simulation, the concentration of organic nitrogen in the top three feet of soil increases from 290 ppm to 370 ppm, a 28% increase. Since no organic nitrogen is added in fertilizer, the increase comes from the recycling of plant residues.

Phosphorus Losses

On an average annual basis, 43.6 lb/ac of phosphorus are applied in fertilizer. Table 8.5 shows average annual phosphorus losses by rotation year. Total average annual losses are only 0.4 lb/ac, or less than 1% of the phosphorus applied annually in fertilizer. Almost all of the losses occur in erosion, and follow the timing of erosion losses.

Over the course of the 40-year simulation, the concentration of labile phosphorus decreased in the top three feet of soil, from 7 ppm to practically nothing. The low concentration of phosphorus in the soil sometimes limits plant growth and lowers crop yield.

Comparison With First Maryland Scenario

It is inevitable that the results of this scenario, where only inorganic fertilizer is used, will be compared with the results of the first Maryland scenario, where both poultry litter and inorganic fertilizer is used. Average annual nitrogen losses are 4.3 lb/ac less and average annual phosphorus losses are 1.8 lb/ac less when only inorganic fertilizer is used. The drop in nitrogen losses represents a 14% decrease in losses. Most of the decrease occurred in erosion losses. Phosphorus losses were low in the first Maryland scenario and almost negligible in this scenario, so further comparison of phosphorus losses would be not be significant.

The two scenarios are not really comparable, however, because the crop rotations are different. Corn, which often has the highest environmental losses, is grown twice as often in the first Maryland scenario than in the second. Total annual nitrogen fertilizer inputs are almost twice as large in the first scenario as the second. Soybeans are grown 50% more often in the second scenario, and the second scenario relies more heavily on nitrogen fixation. Average annual nitrogen fixation is about a third higher in the second scenario. The differences in crop rotation are equally or more significant that the type of fertilizer used, and it would be misleading to compare the environmental impact of litter and inorganic fertilizer on the basis of these two scenarios.

Chapter Nine

Third Maryland Scenario: Poultry and Cash Grain Operation in the Coastal Plain

Scenario Description

The third Maryland scenario represents a three-year crop rotation on a farm that raises poultry and grows cash grain crops. The first year of the rotation is corn double-cropped with wheat, the second year is soybeans, and the third year is sorghum. Both poultry manure and inorganic fertilizer is used in the rotation. This rotation is representative of farms in Dorchester County on Maryland's Eastern Shore. The soil is a Matapeake silt loam, with a 0-2% slope. This soil belongs to Hydrologic Group B. In the simulation, slope is set to 1%.

Table 9.1 shows the schedule of farming operations for the three-year rotation before nutrient management. Corn is planted in April of the first year and harvested in October. Poultry manure is applied the month before planting, and incorporated with a chisel plow. Inorganic starter fertilizer containing both nitrogen and phosphorus is applied at planting. Wheat is planted at the end of October and harvested at the end of the following May. Two top dressings of nitrogen fertilizer, one in February and one in March, are applied to the wheat. Soybeans are planted in June and harvested in November of the second year. No fertilizer or manure is applied to the soybeans. In the third year, sorghum is planted in May and harvested in November. Manure is applied a month before planting and incorporated with a chisel plow. No other fertilizer is applied to the sorghum.

Under nutrient management, the rate of application of manure is reduced. Before nutrient management, 5.0 t/ac of manure are applied before planting the corn and 4.0 t/ac are applied before planting the sorghum. After nutrient management, the rates are reduced to 3.5 t/ac and 2.5 t/ac, respectively. No other change is made in the schedule of farming operations.

Hydrology and Erosion

The simulated hydrology and erosion are almost identical before and after nutrient management, so only the results of the simulations without nutrient management will be discussed. Table 9.2 shows the simulated average annual runoff, lateral flow, percolation, and erosion, as well as the range of annual values of these quantities and their standard deviations. Table 9.3 shows the average annual runoff, lateral flow, percolation, and erosion by rotation year.

The water budget. The same weather data for Cambridge, MD, and Baltimore that was used in the first Maryland scenario was also used in the third scenario. See the discussion above for details.

The simulated average annual precipitation was 44.3 in/ac. Annual evapotranspiration accounts for 29.3 inches or 66% of annual precipitation. Percolation accounts for the next largest component of the water budget. The simulated average annual percolation is 8.8 in/ac, ranging from 3.0 in/ac to 19.6 in/ac annually. Percolation is somewhat less when soybeans are grown in Year 2 than the other rotation years. Figure 9.1 shows the simulated average monthly percolation through the rotation year. Percolation tends to be higher in winter and early spring in all rotation years, and is particularly low throughout the soybean growing season. Lateral flow is minimal in this scenario.

Runoff accounts for the next largest component of the water budget. Simulated average annual runoff is 6.1 in/ac, or 14% of annual precipitation. Runoff is noticeably higher in the third year of rotation, and lower in the second year. Figure 9.2 shows the simulated average monthly runoff throughout the rotation cycle. There is no clear seasonal pattern to runoff.

Erosion. Simulated average annual erosion is 1.1 t/ac, ranging from 0.2 t/ac to 4.0 t/ac annually. Erosion losses are somewhat higher in the first year of the rotation and somewhat lower in the third year. Figure 9.3 shows the simulated average annual monthly erosion throughout the rotation cycle. Erosion tends to be higher in the late spring and summer than in the winter.

Nitrogen Losses

Nitrogen budget before nutrient management. Figure 9.4 shows the major components of the nitrogen budget before nutrient management. Summary statistics for annual values are also shown in Table 9.2.

On an average annual basis, 213.3 lb/ac of nitrogen are applied in fertilizer and manure, 45 lb/ac in ammonium form. 16.7 lb/ac, or 37%, of the ammonium nitrogen are lost in volatilization. Averaged over the whole rotation cycle, 61.7 lb/ac of nitrogen are fixed each year. Thus nitrogen inputs after volatilization amount to 258.3 lb/ac.

The simulated average annual nitrogen content in crop yield is 152.8 lb/ac, or about 60% of annual nitrogen inputs. The nitrogen content in corn yield averages 135 lb/ac per harvest, which, according to the data supplied by Meisinger and Randall, translates into an average yield of 185 bu/ac, close to the target value of 175 bu/ac. The nitrogen content in wheat yield is 75.2 lb/ac. The nitrogen content in soybean yield is 154.4 lb/ac, which translates into average yields of 47 bu/ac, which is above the target yield of 39 bu/ac. 93.7 lb/ac of nitrogen were harvested in sorghum, on average, which, using the data of Meisinger and Randall, amounts to yields of 117 bu/ac, which is below the targeted value of 140 bu/ac.

Table 9.4 shows the average annual nitrogen losses by rotation year. On average, total nitrogen losses were 49.2 lb/ac annually, or less than 20% of nitrogen inputs after volatilization. Nitrogen losses in percolation accounted for the largest portion of environmental nitrogen losses. Simulated average annual nitrogen losses in percolation were 29.5 lb/ac, ranging from no losses to 77.6 lb/ac. Percolation losses were larger than average in Year 1 and smaller than average in Year 2 of the rotation. Nitrogen losses in lateral flow were insignificant. Figure 9.5 shows the average monthly nitrogen losses in lateral flow and percolation Although losses generally follow the seasonal pattern of percolation, with higher losses in the winter and early spring, monthly losses are not necessarily proportional to the average amount of percolation in that month.

Nitrogen losses in runoff constitute the second largest category of environmental losses. Simulated average annual nitrogen losses in runoff were 10.6 lb/ac, ranging from no losses to 25.9

lb/ac annually. Significantly less nitrogen was lost in runoff in the second year of the rotation. Figure 9.6 shows the average monthly nitrogen losses in runoff through the rotation cycle. Higher losses tend to occur in winter and early spring. The lower-than-average losses in Year 2 are due to the presence of the winter wheat cover crop during that time.

Simulated average annual nitrogen losses in erosion are 8.9 lb/ac, ranging from 1.2 lb/ac to 28.6 lb/ac. The average annual losses in the first year of the rotation are more than double the losses in either the second or the third year. Figure 9.7 shows the average monthly nitrogen losses in erosion through the rotation cycle. The seasonal trends in nitrogen losses closely follow the seasonal trends in erosion, both in timing and in relative magnitude. Over the 39-year simulation period, there is a 150 ppm increase in the concentration of organic nitrogen in the soil, from 330 ppm to 480 ppm, which induces a slight increasing trend in nitrogen losses in erosion.

Nitrogen budget after nutrient management. Figure 9.8 shows the major components of the nitrogen budget after nutrient management. After nutrient management, 153.3 lb/ac of nitrogen are applied in fertilizer and manure on an average annual basis, a 28% decrease. 30.0 lb/ac is applied in the form of ammonium, of which 11.2 lb/ac on average volatilize annually. Nitrogen fixation increases by almost 20% after nutrient management. 73.9 lb/ac of nitrogen are fixed per year, averaged over the whole rotation cycle. Average annual nitrogen inputs after volatilization amount to 216.0 lb/ac, a decrease of 16%.

The simulated average annual nitrogen content in crop yield was 151.0 lb/ac, a decrease of less than 2 lb/ac, compared to yields before nutrient management. Nitrogen in crop yield accounts for 70% of annual nitrogen inputs.

Table 9.7 shows the average annual nitrogen losses by rotation year. Total average annual nitrogen losses were 29.0 lb/ac, a 41% decrease, compared to losses before nutrient management. The largest decrease in losses occurred in percolation. Simulated average annual percolation losses decreased by 57%, to 12.6 lb/ac. Losses decreased 10-20 lb/ac in each rotation year.

Losses in lateral flow remained insignificant. Figure 9.9 shows the average monthly nitrogen losses in percolation and lateral flow over the rotation cycle. For the most part, the timing of losses does not differ from the timing of losses before nutrient management. Rather, there is a general decrease in the level of percolation losses throughout the rotation cycle..

Nitrogen losses also decreased in runoff and erosion, but not by as much as in percolation. Simulated average annual nitrogen losses in runoff were 9.0 lb/ac, a decrease of 15%. Annual losses ranged from no losses to 25.9 lb/ac. Losses continued to be significantly lower in the second year of the rotation, and in general follow the same seasonal trends as runoff losses before nutrient management. Simulated average annual nitrogen losses in erosion were 7.4 lb/ac, a decrease of 17%. Annual losses ranged from 1.1 lb/ac to 22.9 lb/ac. Just as they did before nutrient management, nitrogen losses in erosion continue to closely follow the seasonal pattern of erosion losses.

Because of the decrease in amount of manure applied after nutrient management, there was less of a buildup of organic nitrogen in the soil in the course of the simulation. The concentration of organic nitrogen in the top three feet of soil increased by about 100 ppm, from 325 ppm to 430 ppm, an increase of about 30%.

Phosphorus Losses

Before nutrient management, 82.8 lb/ac of phosphorus were applied in manure and fertilizer on an average annual basis. Table 9.5 shows the simulated average annual phosphorus losses for each rotation year before nutrient management. Simulated total average annual phosphorus losses were 4.2 lb/ac, or 5% of applied phosphorus. Three-quarters of the loss occurred in erosion, with most of the rest in runoff. Phosphorus losses in erosion follow the pattern of nitrogen losses in erosion and erosion in general. On average, more phosphorus is lost in erosion in the first year of the rotation. The first year also has the highest overall losses. Over the course of the simulation, the concentration of labile phosphorus in the top three feet of soil increases from 11 ppm to 36 ppm, causing an increasing trend in erosion losses.

After nutrient management, an average of 56.7 lb/ac of phosphorus is applied in fertilizer and manure annually, a decrease of 32% from the annual application rate before nutrient management. The simulated total average annual phosphorus losses are 2.9 lb/ac, or 5% of the applied phosphorus. Although this is the same percentage that was lost before nutrient management, phosphorus losses decreased by 31% after nutrient management, due to the decrease in application rates. Erosion continues to account for more than three-quarters of the losses. For the most part, nutrient management does not change the seasonal pattern of phosphorus losses.

The decreased phosphorus application rate leads to a decrease in the rate of increase in the concentration of labile phosphorus in the top three feet of soil. Over the course of the simulation, the concentration increased from 10 ppm to 24 ppm which is only two-thirds of the final concentration in the simulation without nutrient management.

Effect of Application Rate on Nitrogen Losses

A sensitivity analysis was performed to determine the effect of manure application rates on nitrogen losses. Figure 9.10 shows the simulated average annual nitrogen losses as a function of poultry manure application rates. The bar marked "NM" shows losses under nutrient management. Other bars are labeled by the rate of application to corn and sorghum, respectively, so that "4-3" means 4 t/ac were applied to corn and 3 t/ac were applied to sorghum.

As the figure shows, nitrogen losses increase linearly as a function of application rates. For every additional ton applied in the rotation cycle, 10.7 lb/ac of additional nitrogen is lost per year. Losses in runoff and erosion increase slightly as the application rate is doubled, but most of the increase in losses is in percolation. If it is assumed that approximately one-third of the nitrogen applied as ammonium will volatilize, for every addition ton applied over the rotation cycle, 55 lb/ac of additional nitrogen are added, of which 32.1 lb/ac, or nearly 60%, are lost, mostly in percolation. There is almost no increase in crop yield with increasing application rates. The nitrogen that isn't lost in runoff, erosion, or percolation contributes to a buildup of the concentration of organic nitrogen in the soil.

Sensitivity of Nitrogen Losses to First Year Mineralization Rate

A sensitivity analysis was performed to determine if the fraction of available organic nitrogen applied as nitrate affects nitrogen losses. The rotation was simulated, both before and after nutrient management, at four different levels of nitrate application: (1) none of the available organic nitrogen applied as nitrate, (2) half of the available organic nitrogen applied as nitrate, (3) three-quarters of the available nitrogen applied as nitrate, (4) all of the available nitrogen applied as nitrate. The results are shown in Table 9.10.

As can be expected, as the fraction of available organic nitrogen applied as nitrate increases, less nitrogen is lost in erosion, and more nitrogen is lost in runoff, lateral flow, and percolation. Total nitrogen losses increase with increasing nitrate applications. There is almost a 50% increase in total nitrogen losses in the simulation without nutrient management as the fraction of organic nitrogen applied as nitrate increases from none to 100%. For simulations with nutrient management, the increase is less: losses increase by 29%.

Nitrogen reduction efficiency, however, does not change as much as total losses change when the fraction of organic nitrogen applied as nitrate is increased. Nitrogen reduction efficiency increases with increasing nitrate applications, but efficiencies only range from 39%, when no nitrogen is applied as nitrate, to 47%, when all of the available organic nitrogen is applied as nitrate. In this scenario the effectiveness of nutrient management is not put into question by the assumptions about the mineralization rate of organic nitrogen in poultry manure.

The Effect of Slope on Nutrient Losses and Nutrient Reduction Efficiency

A sensitivity analysis was performed to examine the effect of slope on nutrient losses and nutrient reduction efficiency. The rotation, both before and after nutrient management, was simulated at two additional slopes, 5% and 8%. Table 9.10 shows the average annual runoff, lateral flow, percolation, and erosion for the simulations with different slopes. Only the results before nutrient management are shown. Table 9.11 shows the impact of slope on nitrogen losses and nitrogen reduction efficiency, and Table 9.12 shows the impact on phosphorus losses and phosphorus reduction efficiency.

As the slope varies from 1% to 8%, average annual runoff increases from 6.1 in/ac to 7.9 in/ac, lateral flow increases from 0.1 in/ac, to 0.9 in/ac, and percolation decreases from 8.8 in/ac to 5.9 in/ac. The dominant effect of increasing the slope, however, is increasing average annual erosion from 1.1 t/ac to 6.6 t/ac.

Total nitrogen losses increase with increasing slope. Losses in runoff and lateral flow increase, while losses in percolation decrease, but the increase in nitrogen losses in erosion is the major factor in the increase in total nitrogen losses. Changing the slope from 1% to 8% quadruples nitrogen losses in erosion, both before and after nutrient management. As the slope increases from 1% to 8%, total nitrogen losses increase by 42% in the simulations without nutrient management and by 79% in the simulations under nutrient management. As the slope increases, nutrient management is less effective in reducing nitrogen losses. Nitrogen reduction efficiency drops from 41% at a 1% slope to 26% at an 8% slope.

Phosphorus losses in erosion also quadruple as the slope in the simulations is increased from 1% to 8%. Phosphorus losses in erosion dominate total phosphorus losses regardless of slope. Unlike nitrogen, however, the phosphorus reduction efficiency of nutrient management decreases by only two percent as the slope increases. Lower phosphorus application rates lead to proportionately lower concentrations of phosphorus in the soil, so even as overall losses increase with increasing erosion, proportionately less phosphorus is lost under nutrient management.

Chapter 10

Summary and Conclusions

Quantitative Measures of the Effectiveness of Nutrient Management

The purpose of these computer simulations was to quantify the effectiveness of nutrient management in reducing environmental losses of nitrogen and phosphorus. The results of the simulations demonstrate that nutrient management is very effective in reducing nutrient losses. Table 10.1 shows the nitrogen reduction efficiency and phosphorus reduction efficiency for the five nutrient management scenarios and their variations. The scenarios where there is no clear contrast before and after nutrient management are not represented. Nitrogen reduction efficiencies ranged from 24% to 75%. For those scenarios in which phosphorus inputs were reduced by nutrient management, phosphorus reduction efficiencies ranged from 29% to 52%. Phosphorus inputs are not reduced by nutrient management in the first Maryland scenario.

Table 10.1 also shows the percentage of nitrogen lost as nitrogen in manure is applied above the nutrient management rate. Volatilization losses have been subtracted from the applied rate. Nutrient reduction efficiencies depend in part on the level of nutrient application before nutrient management. While the levels of application represented in these scenarios are typical of practices before nutrient management, it would be helpful to have a measure of the effectiveness of nutrient management that is independent of the the level of nutrient application before nutrient management. The percent of nitrogen lost in manure applications at rates above the level specified by nutrient management was determined to be independent of the rate of manure application. The percent of nitrogen lost from excess manure applications ranges from 9% to 78%. The scenarios in Virginia tend to have low losses. For the scenarios for Pennsylvania and Maryland, the percentage of nitrogen lost ranges from 56% to 78%. For these scenarios, more than half the excess nitrogen applied is lost in erosion, runoff, and subsurface flow. Nutrient management prevents these losses.

Nutrient management does not eliminate nutrient losses. Another measure of the efficiency of nutrient management is how much of the applied nutrients are lost after nutrient management. Table 10.2 shows the simulated total annual average nitrogen and phosphorus losses, the annual phosphorus application, and the average annual nitrogen application after volatilization losses, and the percent of nutrients lost after nutrient management. Phosphorus losses range from 2.2 lb/ac to 10.7 lb/ac annually. Except for the silage corn rotation in the Piedmont Region, total annual average phosphorus losses are 10% or less of phosphorus inputs. After nutrient management, total average annual nitrogen losses range from 29.0 lb/ac to 88.3 lb/ac. Losses tend to be higher in the Pennsylvania scenarios with high nitrogen reduction efficiencies. The percentage of nitrogen lost is always greater than 10%, and ranges as high as 46%. It should be noted, however, that all these scenarios were run with minimal denitrification, which increases the level of nitrogen losses, both before and after nutrient management, especially in the scenarios in Pennsylvania and Maryland where subsurface nitrogen losses dominate. Moreover, as is often pointed out, farming is not like a manufacturing process in which inputs and outputs can be rigorously controlled and the variability in production can be kept within well-defined limits. Crop production is a variable as one of its major inputs: the weather.

The Representational Adequacy of the Computer Simulations

The results of the simulations are only as good as the computer model that produced them, but no computer model is a perfect reflection of reality. It is commonplace in computer modeling to assert that for uncalibrated models like EPIC, even if the simulated values are biased or otherwise subject to error, comparative results are more robust. On this view relative nutrient losses, as measured, for example, by nutrient reduction efficiencies, are more reliable results than the absolute values of nutrient losses themselves. There is probably some truth to this: biases that are linear or near-linear are minimized in comparative measures like nutrient reduction efficiency. Not all biases are linear, however, and there are other types of errors that are not eliminated by comparative measures.

Two general sources of error need to be discussed to give greater validity to the results of the simulations: (1) the mineralization rates of manures, and (2) denitrification. These will be discussed below.

Manure mineralization rates. As explained in Chapter Two, all organic nitrogen in EPIC is represented as mineralizing at the same rate as humus in the soil. Since the soil mineralization rate is much slower than the reported rates for manures, half of the organic nitrogen in manure which becomes available in the first year after application was applied as nitrate. A sensitivity analysis was performed for each simulation to determine the effects on nitrogen losses and nitrogen reduction efficiency of the manure mineralization rate. The simulation were run at three additional levels of nitrate application: no available organic nitrogen applied as nitrate, three-quarters of the available organic nitrogen applied as nitrate, and all of the available organic nitrogen applied as nitrate.

The sensitivity analysis suggests that the potential bias introduced by the choice of manure mineralization rate is the type which can be minimized by using comparative measures like nitrogen reduction efficiency. To repeat for the last time, as the fraction of available nitrogen applied as nitrate increases, losses in runoff and subsurface flow increase, and losses in erosion decrease, since nitrate is lost exclusively in the former and organic nitrogen is lost exclusively in the latter. Overall losses tend to increase. In the third Maryland scenario, for example, nitrate losses in runoff and percolation after nutrient management increase by over 50% as the fraction of available organic nitrogen applied as nitrate increases. Total nitrogen losses increase by almost 30%. Nitrogen reduction efficiency, however, ranges from 39% to 47% as the fraction of available nitrogen applied as nitrate is increased from 0% to 100%. This is the broadest range of reduction efficiencies among the scenarios, outside of the anomaly introduced by the PSNT in the first Maryland scenario. The manure mineralization rate has virtually no effect on the nitrogen reduction efficiency in any of the Pennsylvania scenarios despite differences in total losses of 30% or more over the range of nitrate applications. While nitrogen losses are sensitive to the rate at which organic nitrogen in manure is mineralized to nitrate, the nitrogen reduction efficiency of nutrient management is not.

Denitrification. As was explained in Chapter Two, denitrification was set at a minimum for these simulations. Realistically, more denitrification probably should take place. If denitrification increased, less nitrogen would be lost in percolation and lateral flow. How would it affect the nitrogen reduction efficiency of nutrient management?

To test the effect of increased denitrification on nitrogen reduction efficiency, the following calculation was performed. It was assumed that denitrification losses were proportional to nitrogen losses in percolation and lateral flow. This assumes that denitrification does not effect crop yield; otherwise it is tantamount to assuming that denitrification is proportional to the nitrate content of the soil. The simulation results were used to estimate denitrification and nitrogen reduction efficiency on the assumption that 10%, 20%, and 50% of the subsurface losses with minimal denitrification were the result of denitrification and not environmental losses. This range of losses should cover the range of uncertainty in quantifying denitrification.

The results are shown in Table 10.3. The Virginia scenarios were not used because subsurface nitrogen losses are minimal in those simulations. When 50% of subsurface losses are credited to denitrification, the denitrification rate for the Ridge and Valley Region scenario before nutrient management is approximately 100 lb/ac annually. For the other Pennsylvania scenarios, before nutrient management, the rate would be about 50 lb/ac, and for the Maryland scenarios, before nutrient management the rate would be about 15 lb/ac. As the table shows, nitrogen reduction efficiency is not very sensitive to denitrification rates calculated in this manner. Efficiency drops by 8% when 50% of subsurface losses are credited to denitrification in the Piedmont scenario with a grain corn rotation, and drops by 7% in the third Maryland scenario. Other scenarios are more insensitive. While increased denitrification rates would decrease the losses reported in these simulations, they would not greatly change the reported nitrogen reduction efficiency of nutrient management.

Generalization of Simulation Results

The scenarios simulated in this project are intended to be representative of the agronomic practices in the Chesapeake Bay Basin. It is obvious, however, that there is a greater variety of soils, weather, crop rotations and other practices than represented in these scenarios. Nutrient management has been shown to be effective in reducing nutrient losses in the scenarios simulated, but it is not clear how to extrapolate from these simulations to obtain quantitative estimates of the effectiveness of nutrient management for different crop rotation scenarios using different soils in different parts of the basin. The simulation results suggested factors that might have an impact on nutrient losses, and the effects of slope and soil type were explicitly examined in sensitivity analyzes for each scenario. These provide some guidance for generalizing these results.

The dependence of nitrogen reduction efficiency on scenario-specific factors. An attempt was made to determine whether a simple statistical relation existed between nutrient reduction efficiency and the reduction in nutrient application rates under nutrient management. Nitrogen reduction efficiency was regressed against the percent reduction in nitrogen application rates and the percent reduction in nitrogen application rates above crop yield for all scenarios in which there existed simulations before and after nutrient management. Neither regression yielded a statistically significant relation. The same two regressions were performed for phosphorus with similar results.

Although some simple relation between the reduction of nutrient inputs and the reduction of nutrient losses, different from the two modeled, might exist, it should not be surprising if it did not. In the second Pennsylvania scenario, despite overall similarities between the two rotations, significant differences in losses exist between the grain corn rotation and the silage corn rotation. As was already noted, there is more erosion when silage corn is grown, because there is less ground cover during the period when the soil is vulnerable to erosion. Significant differences also exist in the third Maryland scenario, between those years in which a wheat cover crop is grown and those in which it is not. There are less nutrient losses when soybeans are grown in wheat stubble than when it is grown without a wheat cover crop. The effectiveness of nutrient management depends not only on a crop's demand for nutrients but the position of the crop in a rotation and the condition under which it is grown. Even if a more complex rotation like those used in the Pennsylvania scenarios were used on a Frederick soil in Virginia, the results would not be the same, because of the difference in precipitation between the two regions. In the

Shenandoah Valley, there is much less rainfall, and less water available above crop needs to leach nutrients out of the soil.

In the case of phosphorus, it is easy to see why a simple relation between the reduction in the phosphorus application rate and the phosphorus reduction efficiency does not exist. Almost all phosphorus losses are in erosion. Nutrient management does not change the quantity of erosion, but it does alter the concentration of phosphorus in the soil. If the concentration of phosphorus in the top layer of soil could be predicted on the basis of phosphorus application rates and crop needs, then it would be possible to find a simple relation between the reduction in application rates and phosphorus reduction efficiency. The concentration of phosphorus in the top layer of soil depends on two other factors: soil mixing by tillage operations and the recycling of phosphorus in crop residues. These two factors are dependent on the crop rotation and schedule of farming operations. Thus it is not possible to establish a rotation-independent relation between the reduction in phosphorus application rate and phosphorus reduction efficiency.

Effect of soil type and slope on nutrient losses. In all scenarios, the simulations were performed with different slopes to test the effect of slope on nutrient losses. In the Virginia and Pennsylvania scenarios, the simulations were run on different soils to examine the effects of soil type on nutrient losses. Table 10.4 shows the range of nitrogen reduction efficiencies and total nitrogen losses after nutrient management for both the range of slopes simulated for each scenario and the range of soil types. In all scenarios, losses of nitrogen and phosphorus in erosion, runoff, and lateral flow increased with increasing slope, losses of nitrogen in percolation decreased, and total nitrogen losses increased. The changes in losses reflect the fact that erosion, runoff, and lateral flow increase while percolation decreases with increasing slope. Phosphorus losses are dependent on erosion. Total phosphorus losses increase with increasing slope, but do not change the phosphorus reduction efficiency of nutrient management significantly. Soil type usually changes nutrient losses and nutrient reduction efficiencies by changing the quantities of runoff, subsurface flow, and erosion.

On one reading of the results, it is possible to minimize the impact of slope and soil type on nitrogen reduction efficiency. The change in efficiency with soil type is less than 10% for all scenarios. The change in efficiency with slope is larger than 10% for the Maryland scenarios and the Pennsylvania Piedmont scenarios. Slopes of 5-8%, however, may be untypical for these rotations in the Coastal Plain. Moreover, the changes in efficiency with slope in the Piedmont scenarios are small compared to the size of the reduction efficiencies for these scenarios. In any case, the variation of nitrogen reduction efficiency with soil type is less for different soils or slopes with the same farm rotation schedule than between different farm rotation schedules. The actual crop rotation and the schedule of farm operations are the largest factors in determining nutrient reduction efficiency, and, as a generous rule of thumb, it might be said that crop rotations similar to those represented here will have nutrient reduction efficiencies similar to those reported here for both nitrogen and phosphorus.

Concluding Remarks

It is the goal of the Chesapeake Bay Program to reduce controllable nutrient loads to the Bay by 40%. Nutrient management is a cost-effective method of reducing nutrient loads. In most of the scenarios, edge-of-field nitrogen losses are reduced by more than 40%. Moreover, simulated nitrogen reduction efficiency tends to be higher in those scenarios where losses are higher. It is likely, then, that on average, when weighted by nitrogen losses, that nutrient management reduces nitrogen losses by more than 40%. While the phosphorus reduction efficiency of nutrient management was greater than 40% in fewer scenarios, in all but one of the scenarios where phosphorus inputs were reduced, simulated phosphorus losses after nutrient management were 10% or less of phosphorus inputs, indicating that by another measure of efficiency, nutrient management led to the efficient use of phosphorus. It is fair to say, then, that these simulations support the contention that nutrient management contributes substantially to the effort to reduce controllable nutrient loads to Chesapeake Bay by 40%.

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THE USE OF EPIC TO EVALUATE NUTRIENT LOADS FROM CROP LAND IN THE CHESAPEAKE BAY BASIN

Appendix A: Tables

Ross Mandel
Interstate Commission on the Potomac River Basin
ICPRB Report #97-8
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List of Tables

Table 2.1
Nitrogen Content of Crop Yield (lb/unit measure)
from Meisinger and Randall, 1991

Crop	Unit Measure	Common Value	Range
alfalfa	ton		
early bloom		52	43-60
mid bloom		47	38-55
Full bloom		43	34-51
barley	bushel	0.87	0.78-0.95
corn, grain	bushel	0.73	0.64-0.83
corn, silage	ton	7.2	6.6-8.7
fescue	ton		
late		46	37-54
mid bloom		26	20-31
mature		17	14-20
rye	ton	9	6-12
sorghum	bushel	0.8	0.7-0.87
soybean	bushel	3.3	3.1-3.5
wheat	bushel	1.1	0.95-1.20

Table 2.2
Nutrient Content (lb/t) and Fraction of Organic Nitrogen Available in First Year After Application For Animal Manures and Litters

Scenario	State	Manure Type	Total Kjeldahl Nitrogen	Ammonium Nitrogen	Available Organic Nitrogen	Phosphorus (as P_2O_5)
Poultry and Dairy Operation in Limestone Valley Region	VA	Broiler Litter	60	15	0.6[3]	60
Poultry and Dairy Operation in Limestone Valley Region	VA	Dairy Manure[1]	18	8	0.35[3]	10
Poultry Operation in Limestone Valley Region	VA	Turkey Litter	63	15	0.6[3]	62
Dairy and Swine Operation in Ridge and Valley Region	PA	Dairy Manure	8	2[2]	0.35[4]	3
Dairy and Swine Operation in Ridge and Valley Region	PA	Hog Manure	14	7[2]	0.35[4]	11
Dairy Operation in Piedmont Region	PA	Dairy Manure	10	2.5[2]	0.35[4]	4
Poultry Operation in Coastal Plain	MD	Poultry Litter	60	15	0.5[5]	63
Poultry and Cash Grain Operation in Coastal Plain	MD	Poultry Litter	60	15	0.5[5]	63

1 lbs nutrient/1000 gallons.
2 Estimated based on data in Bandel, 1988.
3 Virginia Nutrient Management Standards and Criteria, 1995.
4 Evanylo, 1994.
5 Li et al., 1995.

Table 3.1
Dairy and Poultry Operation in Limestone Region
Augusta County, VA
Frederick silt loam 7 -15% slope
Continuous Corn Silage/Rye Silage Double Crop
Before Nutrient Management

May 13	Apply broiler litter	5 tons/acre TKN 60lbs/ton NH_4-N 15lbs/ton P_20_5 60lbs/ton
May 16	Apply dairy manure	6000 gal/acre TKN 18lbs/1000 gal NH_4-N 8 lbs/1000 gal P_20_5 10 lbs/1000gal
May 20	Plant corn	
September 5	Chop silage	18 tons/acre
September 30	Apply dairy manure	6000 gal/acre
October 5	Disk	6 in
October 10	Plant rye	
February 12	Apply liquid fertilizer	70 lbs N/acre
May 10	Chop rye silage	7.5 tons/acre

Table 3.2
Dairy and Poultry Operation in Limestone Region Average Annual Hydrology and Nutrient Losses Before Nutrient Management

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	35.6	6.2	49.8	25.6
Runoff (in/ac)	3.1	2.1	9.9	0.1
Lateral Flow (in/ac)	0.9	0.3	1.4	0.4
Percolation (in/ac)	3.1	2.5	9.0	0.0
Evapotranspiration (in/ac)	28.2	2.2	31.6	23.7
Erosion (t/ac)	5.5	3.7	21.2	1.3
P Losses in Erosion (lb/ac)	16.4	8.4	38.8	3.7
P Losses in Runoff (lb/ac)	0.4	0.5	1.8	0.0
P Losses in Percolation (lb/ac)	0.0	0.0	0.1	0.0
N Losses in Erosion (lb/ac)	40.9	21.5	107.3	8.5
N Losses in Runoff (lb/ac)	14.6	14.1	59.8	0.0
N Losses in Lateral Flow (lb/ac)	4.2	1.5	8.0	1.8
N Losses in Percolation (lb/ac)	0.8	2.5	14.3	0.0
Denitrification (lb/ac)	0.8	0.5	2.5	0.2
Ammonia Volatilization (lb/ac)	92.5	1.8	96.4	90.2
Nitrogen in Corn Yield (lb/ac)	147.3	14.0	175.8	120.5
Nitrogen in Rye Yield (lb/ac)	106.1	14.4	133.9	73.2
Fertilizer Nitrogen (lb/ac)	586			

Table 3.3
Dairy and Poultry Operation in Limestone Region
Average Monthly Hydrology
Before Nutrient Management

				(in/ac)		(t/ac)
Month	**Precipitation**	**Runoff**	**Lateral Flow**	**Percolation**	**Evapotranspiration**	**Erosion**
Jan	2.3	0.2	0.1	0.5	0.7	0.0
Feb	2.3	0.3	0.1	0.6	1.0	0.0
Mar	2.9	0.3	0.1	0.9	1.8	0.2
Apr	2.9	0.2	0.1	0.4	3.1	0.2
May	3.5	0.4	0.1	0.1	2.8	0.2
Jun	3.1	0.4	0.1	0.2	3.5	0.5
Jul	3.5	0.1	0.0	0.0	6.6	0.9
Aug	3.3	0.0	0.0	0.0	3.8	0.9
Sep	3.4	0.3	0.1	0.0	1.7	0.7
Oct	3.1	0.4	0.1	0.0	1.2	1.4
Nov	2.7	0.2	0.1	0.1	1.1	0.3
Dec	2.6	0.2	0.1	0.3	0.8	0.1
Annual	35.6	3.1	0.9	3.1	28.2	5.5

Table 3.4
Dairy and Poultry Operation in Limestone Region
Average Monthly Nitrogen Losses
Before Nutrient Management

(lb/ac)

Month	Erosion	Runoff	Lateral Flow	Percolation	Total	Denitrification	Ammonia Volatilization
Jan	0.1	0.0	0.1	0.1	0.3	0.0	0.0
Feb	0.2	6.3	0.5	0.0	7.0	0.0	0.0
Mar	1.0	0.4	0.4	0.4	2.1	0.0	0.1
Apr	0.9	0.1	0.1	0.2	1.2	0.1	0.1
May	2.0	5.6	1.2	0.0	8.7	0.2	53.7
Jun	3.7	1.3	0.6	0.2	5.9	0.2	14.8
Jul	8.5	0.0	0.0	0.0	8.5	0.1	0.4
Aug	8.2	0.0	0.0	0.0	8.2	0.0	0.0
Sep	6.7	0.2	0.1	0.0	7.0	0.0	2.7
Oct	7.3	0.9	0.5	0.0	8.7	0.1	20.2
Nov	1.9	0.0	0.5	0.1	2.5	0.1	0.6
Dec	0.4	0.0	0.3	0.1	0.8	0.0	0.0
Annual	40.9	14.6	4.2	0.8	60.5	0.8	92.5

Table 3.5
Dairy and Poultry Operation in Limestone Region
Average Monthly Phosphorus Losses
Before Nutrient Management

(lb/ac)

Month	Erosion	Runoff	Percolation	Total
Jan	0.0	0.0	0.0	0.0
Feb	0.1	0.0	0.0	0.1
Mar	0.3	0.0	0.0	0.3
Apr	0.3	0.0	0.0	0.3
May	0.9	0.1	0.0	1.0
Jun	1.8	0.2	0.0	2.0
Jul	3.8	0.0	0.0	3.8
Aug	3.5	0.0	0.0	3.5
Sep	2.7	0.1	0.0	2.8
Oct	2.4	0.1	0.0	2.5
Nov	0.6	0.0	0.0	0.6
Dec	0.2	0.0	0.0	0.2
Annual	16.4	0.4	0.0	16.8

Table 3.6
Dairy and Poultry Operation in Limestone Region
Augusta County, VA
Fredrick silt loam 7 -15% slope
Continuous Corn Silage/Rye Silage Double Crop
After Nutrient Management

May 13	Apply broiler litter	3 tons/acre TKN 60lbs/ton NH_4-N 15lbs/ton P_20_5 60lbs/ton
May 16	Apply dairy manure	3000 gal/acre TKN 18lbs/1000 gal NH_4-N 8 lbs/1000 gal P_20_5 10 lbs/1000gal
May 20	Plant corn	
September 5	Chop silage	18 tons/acre
September 30	Apply dairy manure	6000 gal/acre
October 5	Disk	6 in
October 10	Plant rye	
February 12	Apply liquid fertilizer	70 lbs N/acre
May 10	Chop rye silage	7.5 tons/acre

Table 3.7
Dairy and Poultry Operation in Limestone Region Average Annual Hydrology and Nutrient Losses After Nutrient Management

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	35.6	6.2	49.8	25.6
Runoff (in/ac)	3.1	2.1	9.9	0.1
Lateral Flow (in/ac)	0.9	0.3	1.4	0.4
Percolation (in/ac)	3.1	2.5	9.0	0.0
Evapotranspiration (in/ac)	28.2	2.2	31.6	23.7
Erosion (t/ac)	5.7	4.0	23.5	1.4
P Losses in Erosion (lb/ac)	10.6	5.6	27.7	2.2
P Losses in Runoff (lb/ac)	0.1	0.3	0.9	0.0
P Losses in Percolation (lb/ac)	0.0	0.0	0.1	0.0
N Losses in Erosion (lb/ac)	31.1	17.3	92.3	6.6
N Losses in Runoff (lb/ac)	11.9	13.4	58.0	0.0
N Losses in Lateral Flow (lb/ac)	2.9	1.4	7.1	0.9
N Losses in Percolation (lb/ac)	0.4	1.2	5.4	0.0
Denitrification (lb/ac)	0.5	0.4	2.2	0.1
Ammonia Volatilization (lb/ac)	62.3	1.4	65.9	60.1
Nitrogen in Corn Yield (lb/ac)	102.3	23.2	173.1	79.4
Nitrogen in Rye Yield (lb/ac)	95.0	12.4	116.9	55.3
Fertilizer Nitrogen (lb/ac)	406			

Table 3.8
Dairy and Poultry Operation in Limestone Region
Average Monthly Hydrology
After Nutrient Management

			(in/ac)			(t/ac)
Month	**Precipitation**	**Runoff**	**Lateral Flow**	**Percolation**	**Evapotranspiration**	**Erosion**
Jan	2.3	0.2	0.1	0.5	0.7	0.0
Feb	2.3	0.3	0.1	0.6	1.0	0.0
Mar	2.9	0.3	0.1	0.9	1.8	0.2
Apr	2.9	0.2	0.1	0.4	3.1	0.2
May	3.5	0.4	0.1	0.1	2.8	0.3
Jun	3.1	0.4	0.1	0.2	3.5	0.5
Jul	3.5	0.1	0.0	0.0	6.6	1.0
Aug	3.3	0.0	0.0	0.0	3.8	0.9
Sep	3.4	0.3	0.1	0.0	1.7	0.7
Oct	3.1	0.4	0.1	0.0	1.2	1.5
Nov	2.7	0.2	0.1	0.1	1.1	0.4
Dec	2.6	0.2	0.1	0.3	0.8	0.1
Annual	35.6	3.1	0.9	3.1	28.2	5.7

Table 3.9
Dairy and Poultry Operation in Limestone Region Average Monthly Nitrogen Losses After Nutrient Management

(lb/ac)

Month	Erosion	Runoff	Lateral Flow	Percolation	Total	Denitrification	Ammonia Volatilization
Jan	0.1	0.0	0.0	0.0	0.1	0.0	0.0
Feb	0.2	6.3	0.4	0.0	7.0	0.0	0.0
Mar	0.8	0.3	0.3	0.2	1.5	0.0	0.1
Apr	0.7	0.1	0.1	0.1	1.0	0.1	0.1
May	1.6	3.6	0.6	0.0	5.8	0.1	30.3
Jun	2.8	0.7	0.4	0.2	4.0	0.1	8.2
Jul	6.2	0.0	0.0	0.0	6.2	0.1	0.3
Aug	6.0	0.0	0.0	0.0	6.0	0.0	0.0
Sep	4.9	0.2	0.0	0.0	5.1	0.0	2.7
Oct	6.2	0.8	0.5	0.0	7.5	0.1	20.2
Nov	1.5	0.0	0.4	0.0	1.9	0.1	0.6
Dec	0.4	0.0	0.1	0.0	0.4	0.0	0.0
Annual	31.1	11.9	2.9	0.4	46.2	0.5	62.3

Table 3.10
Dairy and Poultry Operation in Limestone Region
Average Monthly Phosphorus Losses
After Nutrient Management

(lb/ac)

Month	Erosion	Runoff	Percolation	Total
Jan	0.0	0.0	0.0	0.0
Feb	0.0	0.0	0.0	0.0
Mar	0.2	0.0	0.0	0.2
Apr	0.2	0.0	0.0	0.2
May	0.6	0.0	0.0	0.6
Jun	1.2	0.1	0.0	1.2
Jul	2.4	0.0	0.0	2.4
Aug	2.2	0.0	0.0	2.2
Sep	1.6	0.0	0.0	1.6
Oct	1.7	0.0	0.0	1.7
Nov	0.4	0.0	0.0	0.4
Dec	0.1	0.0	0.0	0.1
Annual	10.6	0.1	0.0	10.7

Table 3.11
Dairy and Poultry Operation in Limestone Region Sensitivity of Nitrogen Losses and Reduction Efficiency to the Percent of the Organic Nitrogen Available in First Year Represented As Nitrate

	Nitrogen Losses Before Nutrient Management (lb/ac)					Nitrogen Losses After Nutrient Management (lb/ac)					
% Available 1st Year Nitrogen	Erosion	Runoff	Lateral Flow	Percolation	Total	Erosion	Runoff	Lateral Flow	Percolation	Total	Reduction Efficiency
0%	51.0	10.1	2.6	0.4	64.0	37.9	8.9	2.0	0.3	49.1	23%
50%	40.9	14.6	4.2	0.8	60.5	31.1	11.9	2.9	0.4	46.2	24%
75%	35.8	17.3	5.5	1.7	60.2	28.0	13.5	3.4	0.4	45.3	25%
100%	31.9	19.9	7.9	4.7	64.3	25.6	14.8	3.9	0.5	45.0	30%

Table 3.12
Dairy and Poultry Operation in Limestone Region Effect of Slope on Simulated Hydrology

Slope	Runoff (in/ac)	Lateral Flow (in/ac)	Percolation (in/ac)	Erosion (t/ac)
4.5%	2.3	0.5	5.0	1.8
10%	3.1	0.9	3.1	5.5
20%	3.2	1.7	2.5	15.5

Table 3.13
Dairy and Poultry Operation in Limestone Region
Effect of Slope on Simulated Nitrogen Losses and Reduction Efficiency

	Nitrogen Losses Before Nutrient Management (lb/ac)					Nitrogen Losses After Nutrient Management (lb/ac)					
Slope	Erosion	Runoff	Lateral Flow	Percolation	Total	Erosion	Runoff	Lateral Flow	Percolation	Total	Reduction Efficiency
4.5%	17.6	10.3	1.9	0.8	30.5	13.1	7.7	1.2	0.6	22.6	26%
10%	40.9	14.6	4.2	0.8	60.5	31.1	11.9	2.9	0.4	46.2	24%
20%	98.4	17.6	7.3	0.0	123.3	75.1	12.7	5.3	0.0	93.1	25%

Table 3.14
Dairy and Poultry Operation in Limestone Region
Effect of Slope on Simulated Phosphorus Losses and Reduction Efficiency

	Phosphorus Losses Before Nutrient Management (lb/ac)				Phosphorus Losses After Nutrient Management (lb/ac)				
Slope	Erosion	Runoff	Percolation	Total	Erosion	Runoff	Percolation	Total	Reduction Efficiency
4.5%	7.3	0.3	0.0	7.6	4.6	0.0	0.0	4.6	39%
10%	16.4	0.4	0.0	16.8	10.6	0.1	0.0	10.7	36%
20%	40.7	0.3	0.0	41.0	26.2	0.0	0.0	26.2	36%

Table 3.15
Dairy and Poultry Operation in Limestone Region
Effect of Soil Type on Simulated Hydrology

Soil	Hydrologic Group	Slope	Runoff (in/ac)	Lateral Flow (in/ac)	Percolation (in/ac)	Erosion (t/ac)
Frederick silt loam	B	10%	3.1	0.9	3.1	5.5
Timberville silt loam	B	3.5%	2.4	0.4	6.7	0.9
Nixa cherty silt loam	C	10%	5.7	1.3	6.1	1.6

Table 3.16
Dairy and Poultry Operation in Limestone Region
Effect of Soil Type on Simulated Nitrogen Losses and Reduction Efficiency

	Nitrogen Losses Before Nutrient Management (lb/ac)					Nitrogen Losses After Nutrient Management (lb/ac)					
Soil	Erosion	Runoff	Lateral Flow	Percolation	Total	Erosion	Runoff	Lateral Flow	Percolation	Total	Reduction Efficiency
Frederick silt loam	40.9	14.6	4.2	0.8	60.5	31.1	11.9	2.9	0.4	46.2	24%
Timberville silt loam	8.4	10.5	1.7	8.8	29.4	6.5	9.3	1.2	4.5	21.4	27%
Nixa cherty silt loam	12.3	27.4	8.0	16.6	64.3	9.6	24.0	4.9	6.5	45.2	30%

Table 3.17
Dairy and Poultry Operation in Limestone Region
Effect of Soil on Simulated Phosphorus Losses and Reduction Efficiency

	Phosphorus Losses Before Nutrient Management (lb/ac)				Phosphorus Losses After Nutrient Management (lb/ac)				
Soil	Erosion	Runoff	Percolation	Total	Erosion	Runoff	Percolation	Total	Reduction Efficiency
Frederick silt loam	16.4	0.4	0.0	16.8	10.6	0.1	0.0	10.7	36%
Timberville silt loam	3.1	0.3	0.0	3.4	2.1	0.1	0.0	2.1	37%
Nixa cherty silt loam	5.4	1.2	0.0	6.6	3.7	0.5	0.0	4.3	35%

Table 4.1
Poultry Operation in Limestone Region
Augusta County, VA
Frederick silt loam 7 -15% slope
Continuous Fescue/Orchardgrass Hay
Base Case Scenario

April 1	Apply turkey manure	4 tons/acre TKN 63 lbs/ton NH_4-N 15lbs/ton P_20_5 62 lbs/ton
May 20	Cut hay	1.74 tons/acre
July 17	Cut hay	0.75 tons/acre
October 1	Cut hay	1.0 tons/acre

Table 4.2
Poultry Operation in Limestone Region
Alternative Management Scenarios

Alternative Scenario 1	Apply 4 tons of litter January 20
Alternative Scenario 2	Apply 4 tons of litter June 1
Alternative Scenario 3	Apply 4 tons of litter October 5
Alternative Scenario 4	Apply 4 tons of litter November 30
Alternative Scenario 5	Apply 2 tons of litter April 1 and 2 tons on August 1
Alternative Scenario 6	Apply 5 tons on Apri1 1
Alternative Scenario 7	Apply 3 tons on April 1
Alternative Scenario 8	Lower slope to 2-7%
Alternative Scenario 9	Raise slope to 15-25%

Table 4.3
Poultry Operation in Limestone Region
Average Annual Hydrology and Nutrient Losses
Base Case Scenario

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	35.6	6.2	49.8	25.6
Runoff (in/ac)	0.9	0.9	4.3	0.0
Lateral Flow (in/ac)	1.1	0.4	1.8	0.4
Percolation (in/ac)	4.5	3.5	15.1	0.0
Evapotranspiration (in/ac)	28.8	2.2	33.3	23.4
Erosion (t/ac)	0.1	0.1	0.3	0.0
P Losses in Erosion (lb/ac)	0.5	0.5	2.9	0.1
P Losses in Runoff (lb/ac)	0.1	0.3	0.9	0.0
P Losses in Percolation (lb/ac)	0.0	0.0	0.1	0.0
N Losses in Erosion (lb/ac)	1.8	1.7	8.0	0.2
N Losses in Runoff (lb/ac)	0.1	0.4	1.8	0.0
N Losses in Lateral Flow (lb/ac)	2.1	2.6	10.7	0.0
N Losses in Percolation (lb/ac)	0.7	1.7	7.1	0.0
Denitrification (lb/ac)	0.5	0.7	3.5	0.0
Ammonia Volatilization (lb/ac)	36.0	0.6	37.0	34.2
Nitrogen in Hay Yield (lb/ac)	111.3	23.1	175.8	66.0
Fertilizer Nitrogen (lb/ac)	252			

Table 4.4
Poultry Operation in Limestone Region
Average Annual Hydrology and Nutrient Losses
Alternative Scenario 1

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	35.6	6.2	49.8	25.6
Runoff (in/ac)	0.9	0.9	4.3	0.0
Lateral Flow (in/ac)	1.1	0.4	1.8	0.4
Percolation (in/ac)	4.5	3.5	15.1	0.0
Evapotranspiration (in/ac)	28.8	2.2	33.3	23.4
Erosion (t/ac)	0.1	0.1	0.3	0.0
P Losses in Erosion (lb/ac)	0.5	0.5	2.8	0.1
P Losses in Runoff (lb/ac)	0.2	0.4	0.9	0.0
P Losses in Percolation (lb/ac)	0.0	0.0	0.1	0.0
N Losses in Erosion (lb/ac)	1.8	1.7	7.9	0.2
N Losses in Runoff (lb/ac)	2.9	5.8	23.2	0.0
N Losses in Lateral Flow (lb/ac)	2.2	2.7	9.8	0.0
N Losses in Percolation (lb/ac)	0.8	2.0	7.1	0.0
Denitrification (lb/ac)	0.5	0.6	2.8	0.0
Ammonia Volatilization (lb/ac)	35.8	1.0	37.7	33.1
Nitrogen in Hay Yield (lb/ac)	109.3	22.0	174.0	66.0
Fertilizer Nitrogen (lb/ac)	252			

Table 4.5
Poultry Operation in Limestone Region
Average Annual Hydrology and Nutrient Losses
Alternative Scenario 2

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	35.6	6.2	49.8	25.6
Runoff (in/ac)	1.0	0.9	4.3	0.0
Lateral Flow (in/ac)	1.1	0.4	1.8	0.4
Percolation (in/ac)	4.6	3.5	15.3	0.0
Evapotranspiration (in/ac)	28.7	2.2	33.4	23.5
Erosion (t/ac)	0.1	0.1	0.3	0.0
P Losses in Erosion (lb/ac)	0.5	0.5	3.0	0.1
P Losses in Runoff (lb/ac)	0.2	0.4	1.8	0.0
P Losses in Percolation (lb/ac)	0.0	0.0	0.1	0.0
N Losses in Erosion (lb/ac)	1.7	1.6	8.1	0.2
N Losses in Runoff (lb/ac)	0.1	0.3	0.9	0.0
N Losses in Lateral Flow (lb/ac)	2.9	3.2	11.6	0.0
N Losses in Percolation (lb/ac)	0.9	2.4	11.6	0.0
Denitrification (lb/ac)	0.7	0.7	3.4	0.0
Ammonia Volatilization (lb/ac)	34.2	1.2	36.1	30.3
Nitrogen in Hay Yield (lb/ac)	107.0	27.9	178.5	57.1
Fertilizer Nitrogen (lb/ac)	252			

Table 4.6
Poultry Operation in Limestone Region
Average Annual Hydrology and Nutrient Losses
Alternative Scenario 3

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	35.6	6.2	49.8	25.6
Runoff (in/ac)	1.0	0.9	4.3	0.0
Lateral Flow (in/ac)	1.1	0.4	1.9	0.4
Percolation (in/ac)	4.5	3.6	15.4	0.0
Evapotranspiration (in/ac)	28.7	2.2	33.3	23.4
Erosion (t/ac)	0.1	0.1	0.3	0.0
P Losses in Erosion (lb/ac)	0.4	0.4	2.1	0.0
P Losses in Runoff (lb/ac)	0.1	0.4	1.8	0.0
P Losses in Percolation (lb/ac)	0.0	0.0	0.1	0.0
N Losses in Erosion (lb/ac)	1.5	1.5	7.0	0.1
N Losses in Runoff (lb/ac)	0.4	0.9	4.5	0.0
N Losses in Lateral Flow (lb/ac)	2.9	2.9	11.6	0.0
N Losses in Percolation (lb/ac)	0.9	2.1	8.9	0.0
Denitrification (lb/ac)	0.5	0.5	2.7	0.0
Ammonia Volatilization (lb/ac)	34.4	2.2	40.8	28.9
Nitrogen in Hay Yield (lb/ac)	101.5	24.0	171.3	66.0
Fertilizer Nitrogen (lb/ac)	252			

Table 4.7
Poultry Operation in Limestone Region
Average Annual Hydrology and Nutrient Losses
Alternative Scenario 4

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	35.6	6.2	49.8	25.6
Runoff (in/ac)	0.9	0.9	4.3	0.0
Lateral Flow (in/ac)	1.1	0.4	1.8	0.4
Percolation (in/ac)	4.5	3.5	15.1	0.0
Evapotranspiration (in/ac)	28.8	2.2	33.1	23.4
Erosion (t/ac)	0.1	0.1	0.3	0.0
P Losses in Erosion (lb/ac)	0.4	0.4	2.4	0.0
P Losses in Runoff (lb/ac)	0.1	0.3	0.9	0.0
P Losses in Percolation (lb/ac)	0.0	0.0	0.1	0.0
N Losses in Erosion (lb/ac)	1.5	1.5	7.0	0.1
N Losses in Runoff (lb/ac)	0.4	1.1	5.4	0.0
N Losses in Lateral Flow (lb/ac)	2.6	2.5	9.8	0.0
N Losses in Percolation (lb/ac)	0.6	1.7	7.1	0.0
Denitrification (lb/ac)	0.4	0.5	2.5	0.0
Ammonia Volatilization (lb/ac)	32.2	15.6	69.0	1.1
Nitrogen in Hay Yield (lb/ac)	100.8	24.0	172.2	66.0
Fertilizer Nitrogen (lb/ac)	252			

Table 4.8
Poultry Operation in Limestone Region
Average Annual Hydrology and Nutrient Losses
Alternative Scenario 5

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	35.6	6.2	49.8	25.6
Runoff (in/ac)	0.9	0.9	4.3	0.0
Lateral Flow (in/ac)	1.1	0.4	1.8	0.4
Percolation (in/ac)	4.5	3.5	15.2	0.0
Evapotranspiration (in/ac)	28.8	2.2	33.3	23.4
Erosion (t/ac)	0.1	0.1	0.3	0.0
P Losses in Erosion (lb/ac)	0.5	0.4	2.5	0.1
P Losses in Runoff (lb/ac)	0.1	0.4	1.8	0.0
P Losses in Percolation (lb/ac)	0.0	0.0	0.1	0.0
N Losses in Erosion (lb/ac)	1.7	1.6	7.5	0.2
N Losses in Runoff (lb/ac)	0.1	0.4	1.8	0.0
N Losses in Lateral Flow (lb/ac)	2.8	2.7	10.7	0.0
N Losses in Percolation (lb/ac)	0.9	2.1	8.9	0.0
Denitrification (lb/ac)	0.6	0.6	3.3	0.1
Ammonia Volatilization (lb/ac)	34.6	0.5	35.5	32.3
Nitrogen in Hay Yield (lb/ac)	107.4	23.9	174.0	66.0
Fertilizer Nitrogen (lb/ac)	252			

Table 4.9
Poultry Operation in Limestone Region
Average Annual Hydrology and Nutrient Losses
Alternative Scenario 6

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	35.6	6.2	49.8	25.6
Runoff (in/ac)	0.9	0.9	4.3	0.0
Lateral Flow (in/ac)	1.1	0.4	1.8	0.4
Percolation (in/ac)	4.4	3.5	15.1	0.0
Evapotranspiration (in/ac)	28.9	2.2	33.4	23.5
Erosion (t/ac)	0.1	0.1	0.3	0.0
P Losses in Erosion (lb/ac)	0.7	0.7	3.7	0.1
P Losses in Runoff (lb/ac)	0.2	0.4	1.8	0.0
P Losses in Percolation (lb/ac)	0.0	0.0	0.1	0.0
N Losses in Erosion (lb/ac)	2.1	2.1	9.7	0.2
N Losses in Runoff (lb/ac)	0.2	0.5	2.7	0.0
N Losses in Lateral Flow (lb/ac)	3.4	4.1	17.0	0.0
N Losses in Percolation (lb/ac)	1.7	4.6	25.0	0.0
Denitrification (lb/ac)	1.0	1.2	6.1	0.0
Ammonia Volatilization (lb/ac)	45.0	0.7	46.2	42.7
Nitrogen in Hay Yield (lb/ac)	128.0	32.0	207.9	66.0
Fertilizer Nitrogen (lb/ac)	315			

Table 4.10
Poultry Operation in Limestone Region
Average Annual Hydrology and Nutrient Losses
Alternative Scenario 7

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	35.6	6.2	49.8	25.6
Runoff (in/ac)	0.9	0.9	4.3	0.0
Lateral Flow (in/ac)	1.1	0.4	1.8	0.4
Percolation (in/ac)	4.5	3.5	15.1	0.0
Evapotranspiration (in/ac)	28.7	2.2	33.2	23.5
Erosion (t/ac)	0.1	0.1	0.3	0.0
P Losses in Erosion (lb/ac)	0.4	0.4	2.1	0.0
P Losses in Runoff (lb/ac)	0.1	0.2	0.9	0.0
P Losses in Percolation (lb/ac)	0.0	0.0	0.1	0.0
N Losses in Erosion (lb/ac)	1.4	1.3	6.3	0.2
N Losses in Runoff (lb/ac)	0.1	0.3	0.9	0.0
N Losses in Lateral Flow (lb/ac)	1.1	1.5	5.4	0.0
N Losses in Percolation (lb/ac)	0.3	0.8	4.5	0.0
Denitrification (lb/ac)	0.3	0.4	1.2	0.0
Ammonia Volatilization (lb/ac)	26.9	0.4	27.8	25.6
Nitrogen in Hay Yield (lb/ac)	92.3	16.6	152.6	59.8
Fertilizer Nitrogen (lb/ac)	189			

Table 4.11
Poultry Operation in Limestone Region
Average Annual Hydrology and Nutrient Losses
Alternative Scenario 8

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	35.6	6.2	49.8	25.6
Runoff (in/ac)	0.8	0.8	3.8	0.0
Lateral Flow (in/ac)	0.5	0.2	0.9	0.2
Percolation (in/ac)	5.5	3.9	17.0	0.0
Evapotranspiration (in/ac)	28.5	2.1	32.9	23.3
Erosion (t/ac)	0.0	0.0	0.1	0.0
P Losses in Erosion (lb/ac)	0.3	0.4	2.0	0.0
P Losses in Runoff (lb/ac)	0.1	0.3	0.9	0.0
P Losses in Percolation (lb/ac)	0.0	0.0	0.1	0.0
N Losses in Erosion (lb/ac)	0.8	1.0	5.4	0.1
N Losses in Runoff (lb/ac)	0.1	0.2	0.9	0.0
N Losses in Lateral Flow (lb/ac)	0.8	1.2	4.5	0.0
N Losses in Percolation (lb/ac)	1.2	2.8	10.7	0.0
Denitrification (lb/ac)	0.4	0.5	2.6	0.0
Ammonia Volatilization (lb/ac)	36.0	0.6	36.9	34.2
Nitrogen in Hay Yield (lb/ac)	111.5	23.3	176.7	66.0
Fertilizer Nitrogen (lb/ac)	252			

Table 4.12
Poultry Operation in Limestone Region
Average Annual Hydrology and Nutrient Losses
Alternative Scenario 9

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	35.6	6.2	49.8	25.6
Runoff (in/ac)	1.1	1.0	4.6	0.0
Lateral Flow (in/ac)	1.9	0.6	3.3	0.7
Percolation (in/ac)	3.2	3.0	12.8	0.0
Evapotranspiration (in/ac)	29.1	2.2	33.7	23.4
Erosion (t/ac)	0.3	0.2	0.9	0.1
P Losses in Erosion (lb/ac)	1.6	1.2	6.0	0.2
P Losses in Runoff (lb/ac)	0.2	0.4	1.8	0.0
P Losses in Percolation (lb/ac)	0.0	0.0	0.1	0.0
N Losses in Erosion (lb/ac)	4.9	3.8	17.3	0.5
N Losses in Runoff (lb/ac)	0.2	0.5	2.7	0.0
N Losses in Lateral Flow (lb/ac)	3.8	4.5	17.8	0.0
N Losses in Percolation (lb/ac)	0.3	0.8	3.6	0.0
Denitrification (lb/ac)	0.7	0.7	3.7	0.0
Ammonia Volatilization (lb/ac)	36.0	0.6	37.0	34.2
Nitrogen in Hay Yield (lb/ac)	110.6	22.6	174.0	66.0
Fertilizer Nitrogen (lb/ac)	252			

Table 4.13
Poultry Operation in Limestone Region
Average Annual Nitrogen Losses (lb/ac)

Scenario	Erosion	Runoff	Lateral Flow	Percolation	Total	% Base Case
Base Case	1.8	0.1	2.1	0.7	4.5	100%
Alternative Scenario 1	1.8	2.9	2.2	0.8	7.7	169%
Alternative Scenario 2	1.7	0.1	2.9	0.9	5.7	125%
Alternative Scenario 3	1.5	0.4	2.9	0.9	5.5	122%
Alternative Scenario 4	1.5	0.4	2.6	0.6	5.1	112%
Alternative Scenario 5	1.7	0.1	2.8	0.9	5.4	120%
Alternative Scenario 6	2.1	0.2	3.4	1.7	7.3	161%
Alternative Scenario 7	1.4	0.1	1.1	0.3	2.9	63%
Alternative Scenario 8	0.8	0.1	0.8	1.2	2.8	61%
Alternative Scenario 9	4.9	0.2	3.8	0.3	9.2	202%

Table 4.14
Poultry Operation in Limestone Region
Average Annual Phosphorus Losses (lb/ac)

Scenario	Erosion	Runoff	Percolation	Total	% Base Case
Base Case	0.5	0.1	0.0	0.6	100%
Alternative Scenario 1	0.5	0.2	0.0	0.7	114%
Alternative Scenario 2	0.5	0.2	0.0	0.7	114%
Alternative Scenario 3	0.4	0.1	0.0	0.5	86%
Alternative Scenario 4	0.4	0.1	0.0	0.5	86%
Alternative Scenario 5	0.5	0.1	0.0	0.6	100%
Alternative Scenario 6	0.7	0.2	0.0	0.9	143%
Alternative Scenario 7	0.4	0.1	0.0	0.4	71%
Alternative Scenario 8	0.3	0.1	0.0	0.4	57%
Alternative Scenario 9	1.6	0.2	0.0	1.7	271%

Table 4.15
Poultry Operation in Limestone Region
Average Annual Nitrogen Losses (lb/ac)
No Available 1st Year Organic Nitrogen Applied As Nitrate

Scenario	Erosion	Runoff	Lateral Flow	Percolation	Total	% Base Case
Base Case	2.3	0.0	0.7	0.3	3.3	100%
Alternative Scenario 1	2.3	0.1	0.7	0.3	3.4	103%
Alternative Scenario 2	2.1	0.0	0.8	0.3	3.3	100%
Alternative Scenario 3	2.0	0.1	0.8	0.3	3.2	97%
Alternative Scenario 4	2.0	0.1	0.5	0.3	2.8	84%
Alternative Scenario 5	2.2	0.1	0.8	0.3	3.4	103%
Alternative Scenario 6	2.9	0.0	0.9	0.2	3.9	119%
Alternative Scenario 7	1.8	0.0	0.5	0.2	2.5	76%
Alternative Scenario 8	1.1	0.0	0.2	0.4	1.6	49%
Alternative Scenario 9	6.3	0.1	1.4	0.1	7.9	241%

Table 4.16
Poultry Operation in Limestone Region
Average Annual Nitrogen Losses (lb/ac)
Three-Quarters Available 1st Year Organic Nitrogen Applied As Nitrate

Scenario	Erosion	Runoff	Lateral Flow	Percolation	Total	% Base Case
Base Case	1.4	0.2	3.0	1.3	6.0	100%
Alternative Scenario 1	1.4	4.5	3.4	1.4	10.7	179%
Alternative Scenario 2	1.4	0.2	4.4	1.8	7.7	128%
Alternative Scenario 3	1.2	0.5	4.0	1.6	7.4	124%
Alternative Scenario 4	1.2	0.5	3.8	1.2	7.0	116%
Alternative Scenario 5	1.4	0.1	3.8	1.5	7.0	116%
Alternative Scenario 6	1.8	0.3	4.7	2.7	9.5	158%
Alternative Scenario 7	1.2	0.1	1.6	0.4	3.4	57%
Alternative Scenario 8	0.6	0.1	1.3	2.1	4.2	70%
Alternative Scenario 9	4.0	0.3	5.8	0.5	10.6	178%

Table 4.17
Poultry Operation in Limestone Region
Average Annual Nitrogen Losses (lb/ac)
All Available 1st Year Organic Nitrogen Applied As Nitrate

Scenario	Erosion	Runoff	Lateral Flow	Percolation	Total	% Base Case
Base Case	1.2	0.3	4.7	2.5	8.7	100%
Alternative Scenario 1	1.2	6.4	5.0	3.3	16.0	183%
Alternative Scenario 2	1.2	0.2	6.3	2.9	10.5	120%
Alternative Scenario 3	1.1	0.6	5.6	2.9	10.2	116%
Alternative Scenario 4	1.1	0.8	5.7	2.7	10.3	117%
Alternative Scenario 5	1.2	0.2	5.6	2.6	9.6	110%
Alternative Scenario 6	1.5	0.4	8.1	5.4	15.4	177%
Alternative Scenario 7	1.0	0.1	2.5	0.9	4.6	52%
Alternative Scenario 8	0.5	0.1	2.0	4.0	6.6	76%
Alternative Scenario 9	3.4	0.4	8.8	1.2	13.9	159%

Table 4.18
Poultry Operation in Limestone Region
Average Annual Hydrology and Nutrient Losses
Timberville silt loam

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	35.6	6.2	49.8	25.6
Runoff (in/ac)	0.7	0.8	3.9	0.0
Lateral Flow (in/ac)	0.5	0.1	0.7	0.2
Percolation (in/ac)	7.7	4.1	18.5	0.0
Evapotranspiration (in/ac)	26.5	2.3	31.5	20.9
Erosion (t/ac)	0.02	0.01	0.04	0.00
P Losses in Erosion (lb/ac)	0.1	0.1	0.4	0.0
P Losses in Runoff (lb/ac)	0.0	0.2	0.9	0.0
P Losses in Percolation (lb/ac)	0.0	0.0	0.1	0.0
N Losses in Erosion (lb/ac)	0.3	0.3	1.2	0.0
N Losses in Runoff (lb/ac)	0.0	0.2	0.9	0.0
N Losses in Lateral Flow (lb/ac)	0.7	0.9	3.6	0.0
N Losses in Percolation (lb/ac)	4.8	8.8	33.9	0.0
Denitrification (lb/ac)	0.8	1.0	3.7	0.1
Ammonia Volatilization (lb/ac)	40.1	0.4	41.1	39.1
Nitrogen in Corn Yield (lb/ac)	110.5	22.1	163.3	66.0
Fertilizer Nitrogen (lb/ac)	252			

Table 4.19
Poultry Operation in Limestone Region
Average Annual Nitrogen Losses (lb/ac)
Timberville silt loam

Scenario	Erosion	Runoff	Lateral Flow	Percolation	Total	% Base Case
Base Case	0.3	0.0	0.7	4.8	5.8	100%
Alternative Scenario 1	0.3	2.1	0.8	4.8	8.0	138%
Alternative Scenario 2	0.3	0.1	1.1	6.3	7.7	132%
Alternative Scenario 3	0.3	0.2	0.9	5.5	6.8	117%
Alternative Scenario 4	0.3	0.2	0.8	4.5	5.7	98%
Alternative Scenario 5	0.3	0.1	0.9	5.6	6.9	118%
Alternative Scenario 6	0.4	0.1	1.1	7.9	9.4	163%
Alternative Scenario 7	0.3	0.0	0.4	2.7	3.3	57%

Table 4.20
Poultry Operation in Limestone Region
Average Annual Phosphorus Losses (lb/ac)
Timberville silt loam

Scenario	Erosion	Runoff	Percolation	Total	% Base Case
Base Case	0.1	0.0	0.0	0.2	100%
Alternative Scenario 1	0.1	0.1	0.0	0.2	100%
Alternative Scenario 2	0.1	0.0	0.0	0.2	100%
Alternative Scenario 3	0.1	0.0	0.0	0.1	50%
Alternative Scenario 4	0.1	0.0	0.0	0.1	50%
Alternative Scenario 5	0.1	0.0	0.0	0.2	100%
Alternative Scenario 6	0.1	0.1	0.0	0.3	150%
Alternative Scenario 7	0.1	0.0	0.0	0.1	50%

Table 4.21
Poultry Operation in Limestone Region
Average Annual Hydrology and Nutrient Losses
Nixa very cherty silt loam

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	35.6	6.2	49.8	25.6
Runoff (in/ac)	2.8	1.8	7.2	0.2
Lateral Flow (in/ac)	1.5	0.4	2.3	0.7
Percolation (in/ac)	7.3	2.8	16.0	2.0
Evapotranspiration (in/ac)	23.8	2.6	28.4	16.8
Erosion (t/ac)	0.04	0.02	0.08	0.01
P Losses in Erosion (lb/ac)	0.3	0.2	0.8	0.0
P Losses in Runoff (lb/ac)	0.9	1.0	3.6	0.0
P Losses in Percolation (lb/ac)	0.0	0.0	0.1	0.0
N Losses in Erosion (lb/ac)	0.8	0.6	2.9	0.1
N Losses in Runoff (lb/ac)	0.8	1.1	6.2	0.0
N Losses in Lateral Flow (lb/ac)	3.2	2.9	9.8	0.0
N Losses in Percolation (lb/ac)	7.3	10.7	35.7	0.0
Denitrification (lb/ac)	0.6	0.6	2.4	0.1
Ammonia Volatilization (lb/ac)	40.1	0.5	41.1	38.8
Nitrogen in Hay Yield (lb/ac)	97.8	19.7	139.2	61.6
Fertilizer Nitrogen (lb/ac)	252			

Table 4.22
Poultry Operation in Limestone Region
Average Annual Nitrogen Losses (lb/ac)
Nixa very cherty silt loam

Scenario	Erosion	Runoff	Lateral Flow	Percolation	Total	% Base Case
Base Case	0.8	0.8	3.2	7.3	12.0	100%
Alternative Scenario 1	0.8	7.1	3.2	7.0	18.2	151%
Alternative Scenario 2	0.8	0.9	5.1	11.4	18.2	151%
Alternative Scenario 3	0.7	1.4	3.7	7.7	13.7	114%
Alternative Scenario 4	0.7	1.5	3.9	6.8	12.9	107%
Alternative Scenario 5	0.8	1.2	4.3	8.3	14.5	121%
Alternative Scenario 6	1.0	1.1	5.1	11.5	18.6	155%
Alternative Scenario 7	0.6	0.5	1.8	4.6	7.7	64%
Alternative Scenario 8	0.4	0.4	1.2	9.4	11.4	95%
Alternative Scenario 9	2.2	1.1	6.2	4.8	14.3	119%

Table 4.23
Poultry Operation in Limestone Region
Average Annual Phosphorus Losses (lb/ac)
Nixa very cherty silt loam

Scenario	Erosion	Runoff	Percolation	Total	% Base Case
Base Case	0.3	0.9	0.0	1.2	100%
Alternative Scenario 1	0.3	1.0	0.0	1.2	108%
Alternative Scenario 2	0.3	1.0	0.0	1.2	108%
Alternative Scenario 3	0.2	0.8	0.0	1.1	92%
Alternative Scenario 4	0.2	0.8	0.0	1.1	92%
Alternative Scenario 5	0.3	0.9	0.0	1.2	100%
Alternative Scenario 6	0.4	1.3	0.0	1.7	146%
Alternative Scenario 7	0.2	0.5	0.0	0.7	62%
Alternative Scenario 8	0.1	0.6	0.0	0.8	69%
Alternative Scenario 9	0.7	1.1	0.0	1.8	154%

Table 5.1
Swine and Dairy Operation in Ridge and Valley Region
Dauphin County, PA near Elizabethsville
Calvin-Leck Kill shaly silt loam, 3 to 8 percent slope
Nine-Year Rotation With Dairy Manure Before Nutrient Management

Year 1

April 15	Manure	8-3-6 lbs/ton @ 30 tons/ac
April 20	Chisel Plow	6-8 in
April 25	Plant Corn Silage	
April 25	Starter Fertilizer	10.4 N -21 P2O5 lbs/ac
June 5	Sidedress Fertilizer	50 lbs/ac N
Sept 15	Harvest Corn Silage	
Sept 20	Manure	8-3-6 lbs/ton @ 30 tons/ac
Sept 20	Disk or Chisel Plow	6-8 in
Sept 25	Plant Rye	

Year 2

May 5	Harvest Rye	
May 10	Manure	8-3-6 lbs/ton @ 30 tons/ac
May 15	Starter Fertilizer	10.4 N -21 P2O5 lbs/ac
May 15	Plant Corn	
June 15	Sidedress Fertilizer	50 lbs/ac N
Oct 25	Harvest Corn	

Year 3

April 15	Manure	8-3-6 lbs/ton @ 30 tons/ac

Table 5.1
Swine and Dairy Operation in Ridge and Valley Region
Dauphin County, PA near Elizabethsville
Calvin-Leck Kill shaly silt loam, 3 to 8 percent slope
Nine-Year Rotation With Dairy Manure Before Nutrient Management

April 25	Starter Fertilizer	10.4 N -21 P2O5 lbs/ac
April 25	Plant Corn	
June 5	Sidedress Fertilizer	50 lbs/ac N
Oct 25	Harvest Corn	

Year 4

April 15	Manure	8-3-6 lbs/ton @ 30 tons/ac
April 25	Plant Corn Silage	
April 25	Starter Fertilizer	10.4 N -21 P2O5 lbs/ac
June 5	Sidedress Fertilizer	50 lbs/ac N
Sept 15	Harvest Corn Silage	
Sept 15	Manure	8-3-6 lbs/ton @ 30 tons/ac
Sept 20	Disk or Chisel Plow	6-8 in
Sept 25	Plant Barley	

Year 5

June 15	Harvest Barley	
July 25	Manure	8-3-6 lbs/ton @ 30 tons/ac
Aug 5	Moldboard or Chisel Plow	
Aug 15	Plant Alfalfa	

Year 6

Table 5.1
Swine and Dairy Operation in Ridge and Valley Region
Dauphin County, PA near Elizabethsville
Calvin-Leck Kill shaly silt loam, 3 to 8 percent slope
Nine-Year Rotation With Dairy Manure Before Nutrient Management

July 25	Cut Alfalfa	
Sept 5	Cut Alfalfa	
Sept 25	Manure	8-3-6 lbs/ton @ 30 tons/ac

Year 7

May 15	Cut Alfalfa	
June 25	Cut Alfalfa	
Aug 5	Cut Alfalfa	
Sept 15	Cut Alfalfa	
Sept 25	Manure	8-3-6 lbs/ton @ 30 tons/ac

Year 8

May 15	Cut Alfalfa	
June 25	Cut Alfalfa	
Aug 5	Cut Alfalfa	
Aug 10	Fertilize	0-10-40 @ 300lbs/ac
Sept 15	Cut Alfalfa	
Sept 25	Manure	8-3-6 lbs/ton @ 30 tons/ac

Year 9

May 15	Cut Alfalfa	
June 25	Cut Alfalfa	

Table 5.1
Swine and Dairy Operation in Ridge and Valley Region
Dauphin County, PA near Elizabethsville
Calvin-Leck Kill shaly silt loam, 3 to 8 percent slope
Nine-Year Rotation With Dairy Manure Before Nutrient Management

Aug 5	Cut Alfalfa	
Aug 10	Fertilize	0-10-40 @ 300lbs/ac
Sept 15	Cut Alfalfa	
Sept 25	Manure	8-3-6 lbs/ton @ 30 tons/ac

Table 5.2
Swine and Dairy Operation in Ridge and Valley Region
Average Annual Hydrology and Nutrient Losses
Dairy Manure Before Nutrient Management

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	39.1	6.5	59.3	27.3
Runoff (in/ac)	5.0	3.5	20.8	0.6
Lateral Flow (in/ac)	0.8	0.2	1.2	0.4
Percolation (in/ac)	11.8	3.5	19.9	4.8
Evapotranspiration (in/ac)	21.5	2.6	28.3	14.9
Erosion (t/ac)	0.9	1.1	4.6	0.0
P Losses in Erosion (lb/ac)	2.7	3.2	14.9	0.1
P Losses in Runoff (lb/ac)	0.7	0.9	4.5	0.0
P Losses in Percolation (lb/ac)	0.2	0.1	0.3	0.1
N Losses in Erosion (lb/ac)	17.8	21.9	112.3	0.4
N Losses in Runoff (lb/ac)	7.8	8.5	33.9	0.0
N Losses in Lateral Flow (lb/ac)	5.4	2.1	10.7	0.9
N Losses in Percolation (lb/ac)	106.0	50.6	233.8	4.5
Denitrification (lb/ac)	2.7	1.3	5.4	0.7
Ammonia Volatilization (lb/ac)	38.2	10.5	61.7	25.5
Nitrogen Fixation (lb/ac)	91.5	96.2	111.0	22.8
Nitrogen in Corn Yield (lb/ac)	116.1	43.9	205.2	12.5
Nitrogen in Rye Yield (lb/ac)	24.5	7.8	36.6	14.3
Nitrogen in Barley Yield (lb/ac)	62.7	12.4	83.0	41.9
Nitrogen in Alfalfa Yield (lb/ac)	206.7	70.1	274.0	34.8
Fertilizer Nitrogen (lb/ac)	320.2			

Table 5.3
Swine and Dairy Operation in Ridge and Valley Region Average Annual Hydrology and Erosion For Rotation Years Dairy Manure Before Nutrient Management

Rotation Year	Runoff (in/ac)	Lateral Flow (in/ac)	Percolation (in/ac)	Erosion (t/ac)
Year 1	4.9	0.8	12.4	1.5
Year 2	7.9	0.7	10.3	1.4
Year 3	8.9	0.7	11.0	2.0
Year 4	7.0	0.7	11.4	1.7
Year 5	5.4	0.7	10.8	1.2
Year 6	2.7	0.8	11.3	0.3
Year 7	2.2	0.8	11.9	0.1
Year 8	2.8	0.8	12.7	0.2
Year 9	3.6	0.9	15.0	0.2

Table 5.4
Swine and Dairy Operation in Ridge and Valley Region Average Annual Nitrogen Losses For Rotation Years Dairy Manure Before Nutrient Management

	Nitrogen Losses (lb/ac)				
Rotation Year	**Erosion**	**Runoff**	**Lateral Flow**	**Percolation**	**Total**
Year 1	32.7	10.1	7.1	113.1	163.0
Year 2	26.4	9.2	4.2	76.2	116.0
Year 3	34.9	21.7	5.9	110.0	172.5
Year 4	31.2	18.8	7.1	125.7	182.9
Year 5	18.3	3.6	5.4	100.0	127.3
Year 6	5.0	3.5	6.3	153.4	168.2
Year 7	2.2	0.8	4.7	114.6	122.3
Year 8	4.6	0.6	3.3	75.3	83.9
Year 9	5.3	1.9	4.2	86.0	97.4
Average	17.8	7.8	5.4	106.0	137.1

Table 5.5
Swine and Dairy Operation in Ridge and Valley Region
Average Annual Phosphorus Losses For Rotation Years
Dairy Manure Before Nutrient Management

	Phosphorus Losses (lb/ac)			
Rotation Year	**Erosion**	**Runoff**	**Percolation**	**Total**
Year 1	4.5	1.0	0.2	5.6
Year 2	4.2	1.2	0.2	5.5
Year 3	5.6	1.7	0.2	7.5
Year 4	5.0	1.4	0.2	6.6
Year 5	2.1	0.4	0.2	2.7
Year 6	0.5	0.0	0.2	0.7
Year 7	0.3	0.0	0.2	0.4
Year 8	0.6	0.0	0.2	0.8
Year 9	0.8	0.9	0.2	1.9
Average	2.7	0.7	0.2	3.5

Table 5.6
Swine and Dairy Operation in Ridge and Valley Region
Average Annual Hydrology and Nutrient Losses
Hog Manure Before Nutrient Management

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	39.1	6.5	59.3	27.3
Runoff (in/ac)	5.0	3.5	20.8	0.6
Lateral Flow (in/ac)	0.8	0.2	1.2	0.4
Percolation (in/ac)	11.7	3.5	19.9	4.8
Evapotranspiration (in/ac)	21.6	2.6	28.3	14.9
Erosion (t/ac)	0.9	1.1	4.6	0.0
P Losses in Erosion (lb/ac)	6.2	7.5	36.2	0.1
P Losses in Runoff (lb/ac)	2.9	2.6	15.2	0.0
P Losses in Percolation (lb/ac)	0.2	0.1	0.4	0.1
N Losses in Erosion (lb/ac)	20.4	25.3	129.7	0.4
N Losses in Runoff (lb/ac)	10.8	11.3	41.9	0.0
N Losses in Lateral Flow (lb/ac)	9.5	3.2	17.0	2.7
N Losses in Percolation (lb/ac)	191.8	76.1	390.8	41.0
Denitrification (lb/ac)	4.6	2.2	10.6	1.2
Ammonia Volatilization (lb/ac)	134.3	37.0	215.1	89.9
Nitrogen Fixation (lb/ac)	87.3	92.6	104.0	22.8
Nitrogen in Corn Yield (lb/ac)	117.4	45.0	205.2	12.5
Nitrogen in Rye Yield (lb/ac)	27.7	7.9	39.3	16.1
Nitrogen in Barley Yield (lb/ac)	69.0	12.6	84.8	46.4
Nitrogen in Alfalfa Yield (lb/ac)	207.0	70.4	274.8	34.8
Fertilizer Nitrogen (lb/ac)	534.6			

Table 5.7
Swine and Dairy Operation in Ridge and Valley Region Average Annual Nitrogen Losses For Rotation Years Hog Manure Before Nutrient Management

	Nitrogen Losses (lb/ac)				
Rotation Year	**Erosion**	**Runoff**	**Lateral Flow**	**Percolation**	**Total**
Year 1	37.7	15.4	12.8	199.3	265.3
Year 2	30.1	13.3	9.0	191.1	243.4
Year 3	40.2	28.6	9.3	192.2	270.2
Year 4	36.0	26.0	12.5	214.2	288.6
Year 5	20.4	5.0	9.9	212.9	248.3
Year 6	5.5	4.2	9.7	230.8	250.2
Year 7	2.5	1.2	8.6	198.5	210.7
Year 8	5.3	1.2	6.0	129.7	142.2
Year 9	6.2	2.6	7.5	157.1	173.3
Average	20.4	10.8	9.5	191.8	232.5

Table 5.8
Swine and Dairy Operation in Ridge and Valley Region Average Annual Phosphorus Losses For Rotation Years Hog Manure Before Nutrient Management

	Phosphorus Losses (lb/ac)			
Rotation Year	**Erosion**	**Runoff**	**Percolation**	**Total**
Year 1	11.0	3.5	0.2	14.6
Year 2	10.0	4.8	0.2	15.0
Year 3	13.2	5.9	0.2	19.3
Year 4	11.8	4.2	0.2	16.2
Year 5	4.7	2.1	0.2	7.0
Year 6	1.2	0.4	0.2	1.7
Year 7	0.7	0.9	0.2	1.8
Year 8	1.7	1.5	0.2	3.4
Year 9	2.0	2.9	0.3	5.2
Average	6.2	2.9	0.2	9.3

Table 5.9
Swine and Dairy Operation in Ridge and Valley Region
Dauphin County, PA near Elizabethsville
Calvin-Leck Kill shaly silt loam, 3 to 8 percent slope
Nine-Year Rotation With Dairy Manure After Nutrient Management

Year 1

April 15	Manure	8-3-6 lbs/ton @ 20 tons/ac
April 20	Chisel Plow	6-8 in
April 25	Plant Corn Silage	
April 25	Starter Fertilizer	5.2 N -10.5 P2O5 lbs/ac
Sept 15	Harvest Corn Silage	
Sept 20	Manure	8-3-6 lbs/ton @ 20 tons/ac
Sept 20	Disk or Chisel Plow	
Sept 25	Plant Rye	

Year 2

May 5	Harvest Rye	
May 10	Manure	8-3-6 lbs/ton @ 20 tons/ac
May 15	Starter Fertilizer	5.2 N -10.5 P2O5 lbs/ac
May 15	Plant Corn	
June 15	Sidedress Fertilizer	30-35 lbs/ac N
Oct 25	Harvest Corn	

Year 3

April 15	Manure	8-3-6 lbs/ton @ 20 tons/ac

Table 5.9
Swine and Dairy Operation in Ridge and Valley Region
Dauphin County, PA near Elizabethsville
Calvin-Leck Kill shaly silt loam, 3 to 8 percent slope
Nine-Year Rotation With Dairy Manure After Nutrient Management

April 25	Starter Fertilizer	5.2-10.5 lbs/ac
April 25	Plant Corn	
June 5	Sidedress Fertilizer	30-35 lbs/ac N
Oct 25	Harvest Corn	

Year 4

April 15	Manure	8-3-6 lbs/ton @ 20 tons/ac
April 25	Plant Corn Silage	
April 25	Starter Fertilizer	5.2-10.5 lbs/ac
June 5	Sidedress Fertilizer	30-35 lbs/ac N
Sept 15	Harvest Corn Silage	
Sept 20	Manure	8-3-6 lbs/ton @ 20 tons/ac
Sept 20	Disk or Chisel Plow	6-8 in
Sept 25	Plant Barley	

Year 5

June 15	Harvest Barley	
July 25	Manure	8-3-6 lbs/ton @ 20 tons/ac
Aug 5	Moldboard or Chisel Plow	
Aug 15	Plant Alfalfa	

Year 6

Table 5.9
Swine and Dairy Operation in Ridge and Valley Region
Dauphin County, PA near Elizabethsville
Calvin-Leck Kill shaly silt loam, 3 to 8 percent slope
Nine-Year Rotation With Dairy Manure After Nutrient Management

July 25	Cut Alfalfa	
Sept 5	Cut Alfalfa	
Sept 25	Manure	8-3-6 lbs/ton @ 20 tons/ac

Year 7

May 15	Cut Alfalfa	
June 25	Cut Alfalfa	
Aug 5	Cut Alfalfa	
Sept 15	Cut Alfalfa	
Sept 25	Manure	8-3-6 lbs/ton @ 20 tons/ac

Year 8

May 15	Cut Alfalfa	
June 25	Cut Alfalfa	
Aug 5	Cut Alfalfa	
Aug 10	Fertilize	0-10-40 @ 300lbs/ac
Sept 15	Cut Alfalfa	
Sept 25	Manure	8-3-6 lbs/ton @ 20 tons/ac

Year 9

May 15	Cut Alfalfa	
June 25	Cut Alfalfa	

Table 5.9
Swine and Dairy Operation in Ridge and Valley Region
Dauphin County, PA near Elizabethsville
Calvin-Leck Kill shaly silt loam, 3 to 8 percent slope
Nine-Year Rotation With Dairy Manure After Nutrient Management

Aug 5	Cut Alfalfa	
Aug 10	Fertilize	0-10-40 @ 300lbs/ac
Sept 15	Cut Alfalfa	
Sept 25	Manure	8-3-6 lbs/ton @ 20 tons/ac

Table 5.10
Swine and Dairy Operation in Ridge and Valley Region
Average Annual Hydrology and Nutrient Losses
Dairy Manure After Nutrient Management

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	39.1	6.5	59.3	27.3
Runoff (in/ac)	4.8	3.2	19.2	0.6
Lateral Flow (in/ac)	0.8	0.2	1.2	0.4
Percolation (in/ac)	11.9	3.5	19.9	4.5
Evapotranspiration (in/ac)	21.6	2.6	28.3	14.9
Erosion (t/ac)	1.0	1.1	4.6	0.0
P Losses in Erosion (lb/ac)	2.1	2.4	11.2	0.1
P Losses in Runoff (lb/ac)	0.3	0.5	2.7	0.0
P Losses in Percolation (lb/ac)	0.2	0.1	0.3	0.1
N Losses in Erosion (lb/ac)	15.3	18.1	91.7	0.4
N Losses in Runoff (lb/ac)	5.1	5.4	19.6	0.0
N Losses in Lateral Flow (lb/ac)	2.9	1.3	6.2	0.9
N Losses in Percolation (lb/ac)	55.1	31.5	139.2	0.9
Denitrification (lb/ac)	1.4	0.6	2.9	0.4
Ammonia Volatilization (lb/ac)	25.5	6.3	40.2	19.5
Nitrogen Fixation (lb/ac)	96.2	101.8	112.7	22.8
Nitrogen in Corn Yield (lb/ac)	106.6	39.0	191.0	12.5
Nitrogen in Rye Yield (lb/ac)	20.8	5.7	31.2	13.4
Nitrogen in Barley Yield (lb/ac)	54.3	10.7	71.4	36.6
Nitrogen in Alfalfa Yield (lb/ac)	205.6	69.6	273.1	33.9
Fertilizer Nitrogen (lb/ac)	207.9			

Table 5.11
Swine and Dairy Operation in Ridge and Valley Region
Average Annual Nitrogen Losses For Rotation Years
Dairy Manure After Nutrient Management

		Nitrogen Losses (lb/ac)			
Rotation Year	**Erosion**	**Runoff**	**Lateral Flow**	**Percolation**	**Total**
Year 1	27.3	5.7	3.7	58.4	95.0
Year 2	22.5	4.8	1.7	22.0	51.0
Year 3	28.5	11.9	3.0	48.5	91.9
Year 4	24.7	13.3	3.6	55.7	97.3
Year 5	18.0	3.8	2.9	47.8	72.6
Year 6	5.5	3.6	4.5	97.8	111.4
Year 7	2.1	0.4	3.0	68.8	74.3
Year 8	4.4	0.6	2.1	45.9	52.9
Year 9	4.8	1.5	2.3	50.6	59.3
Average	15.3	5.1	2.9	55.1	78.4

Table 5.12
Swine and Dairy Operation in Ridge and Valley Region
Average Annual Phosphorus Losses For Rotation Years
Dairy Manure After Nutrient Management

	Phosphorus Losses (lb/ac)			
Rotation Year	**Erosion**	**Runoff**	**Percolation**	**Total**
Year 1	3.4	0.3	0.2	3.8
Year 2	3.2	0.4	0.2	3.7
Year 3	4.2	0.8	0.2	5.2
Year 4	3.7	0.5	0.2	4.4
Year 5	2.2	0.3	0.2	2.7
Year 6	0.6	0.0	0.2	0.8
Year 7	0.3	0.0	0.2	0.4
Year 8	0.5	0.0	0.2	0.7
Year 9	0.6	0.1	0.2	0.9
Average	2.1	0.3	0.2	2.5

Table 5.13
Swine and Dairy Operation in Ridge and Valley Region
Average Annual Hydrology and Nutrient Losses
Hog Manure After Nutrient Management

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	39.1	6.5	59.3	27.3
Runoff (in/ac)	5.0	3.5	20.8	0.6
Lateral Flow (in/ac)	0.8	0.2	1.2	0.4
Percolation (in/ac)	11.7	3.5	19.8	4.8
Evapotranspiration (in/ac)	21.6	2.6	28.3	15.0
Erosion (t/ac)	1.0	1.1	4.5	0.0
P Losses in Erosion (lb/ac)	3.8	4.4	21.2	0.1
P Losses in Runoff (lb/ac)	1.3	1.2	7.1	0.0
P Losses in Percolation (lb/ac)	0.2	0.1	0.3	0.1
N Losses in Erosion (lb/ac)	14.7	17.3	87.5	0.4
N Losses in Runoff (lb/ac)	5.1	5.2	19.6	0.0
N Losses in Lateral Flow (lb/ac)	3.6	1.5	6.2	0.9
N Losses in Percolation (lb/ac)	65.0	35.4	157.9	3.6
Denitrification (lb/ac)	1.5	0.6	3.0	0.4
Ammonia Volatilization (lb/ac)	67.9	18.2	109.3	51.7
Nitrogen Fixation (lb/ac)	95.5	101.1	112.4	22.8
Nitrogen in Corn Yield (lb/ac)	105.4	38.7	179.4	12.5
Nitrogen in Rye Yield (lb/ac)	22.6	6.9	34.8	13.4
Nitrogen in Barley Yield (lb/ac)	57.7	11.8	76.7	38.4
Nitrogen in Alfalfa Yield (lb/ac)	205.7	69.7	274.0	33.9
Fertilizer Nitrogen (lb/ac)	256.7			

Table 5.14
Swine and Dairy Operation in Ridge and Valley Region Average Annual Nitrogen Losses For Rotation Years Hog Manure After Nutrient Management

	Nitrogen Losses (lb/ac)				
Rotation Year	**Erosion**	**Runoff**	**Lateral Flow**	**Percolation**	**Total**
Year 1	26.3	7.0	5.0	79.4	117.8
Year 2	21.3	4.6	1.5	30.6	58.0
Year 3	27.2	12.4	2.8	40.8	83.2
Year 4	24.3	12.0	3.8	51.7	91.7
Year 5	17.2	3.2	3.9	61.9	86.3
Year 6	5.3	3.7	5.1	113.6	127.6
Year 7	2.1	0.6	3.7	85.3	91.7
Year 8	4.2	0.8	2.9	56.8	64.7
Year 9	4.6	1.5	3.0	64.5	73.7
Average	14.7	5.1	3.6	65.0	88.3

Table 5.15
Swine and Dairy Operation in Ridge and Valley Region
Average Annual Phosphorus Losses For Rotation Years
Hog Manure After Nutrient Management

	Phosphorus Losses (lb/ac)			
Rotation Year	**Erosion**	**Runoff**	**Percolation**	**Total**
Year 1	6.5	1.5	0.2	8.2
Year 2	5.8	2.1	0.2	8.1
Year 3	7.5	2.7	0.2	10.4
Year 4	6.5	1.8	0.2	8.5
Year 5	3.7	0.8	0.2	4.6
Year 6	1.2	0.3	0.2	1.6
Year 7	0.5	0.5	0.2	1.2
Year 8	1.2	0.8	0.2	2.1
Year 9	1.3	1.5	0.2	3.0
Average	3.8	1.3	0.2	5.3

Table 5.16
Swine and Dairy Operation in Ridge and Valley Region Sensitivity of Nitrogen Losses and Reduction Efficiency to the Percent of the Organic Nitrogen Available in First Year Dairy Manure Represented As Nitrate

	Nitrogen Losses Before Nutrient Management (lb/ac)					Nitrogen Losses After Nutrient Management (lb/ac)					
% Available 1st Year Nitrogen	Erosion	Runoff	Lateral Flow	Percolation	Total	Erosion	Runoff	Lateral Flow	Percolation	Total	Reduction Efficiency
0%	19.9	6.4	4.4	89.9	120.6	16.9	4.1	2.4	45.7	69.1	43%
50%	17.8	7.8	5.4	106.0	137.1	15.3	5.1	2.9	55.1	78.4	43%
75%	16.6	8.4	6.0	115.6	146.5	14.4	5.5	3.3	60.1	83.3	43%
100%	15.8	9.1	6.7	128.1	159.6	13.7	6.0	3.7	67.7	91.2	43%

Table 5.17
Swine and Dairy Operation in Ridge and Valley Region Sensitivity of Nitrogen Losses and Reduction Efficiency to the Percent of the Organic Nitrogen Available in First Year Hog Manure Represented As Nitrate

	Nitrogen Losses Before Nutrient Management (lb/ac)					Nitrogen Losses After Nutrient Management (lb/ac)					
% Available 1st Year Nitrogen	Erosion	Runoff	Lateral Flow	Percolation	Total	Erosion	Runoff	Lateral Flow	Percolation	Total	Reduction Efficiency
0%	22.1	9.5	8.7	177.4	217.8	15.6	4.4	3.2	58.8	81.9	62%
50%	20.4	10.8	9.5	191.8	232.5	14.7	5.1	3.6	65.0	88.3	62%
75%	19.2	11.4	9.9	199.6	240.1	14.0	5.4	3.7	68.4	91.6	62%
100%	18.3	12.0	10.4	206.9	247.7	13.6	5.8	4.0	71.7	95.1	62%

Table 5.18
Swine and Dairy Operation in Ridge and Valley Region
Effect of Slope on Simulated Hydrology
Dairy Manure

Slope	Runoff (in/ac)	Lateral Flow (in/ac)	Percolation (in/ac)	Erosion (t/ac)
%2	4.4	0.3	13.2	0.4
%5	5.0	0.8	11.7	0.9
%10	5.8	1.4	10.0	2.5

Table 5.19
Swine and Dairy Operation in Ridge and Valley Region
Effect of Slope on Simulated Nitrogen Losses and Reduction Efficiency
Dairy Manure

	Nitrogen Losses Before Nutrient Management (lb/ac)					Nitrogen Losses After Nutrient Management (lb/ac)					
Slope	Erosion	Runoff	Lateral Flow	Percolation	Total	Erosion	Runoff	Lateral Flow	Percolation	Total	Reduction Efficiency
%2	8.2	6.1	2.0	114.6	130.8	7.1	3.9	1.0	60.9	73.0	44%
%5	17.8	7.8	5.4	106.0	137.1	15.3	5.1	2.9	55.1	78.4	43%
%10	40.3	10.2	10.4	92.4	153.3	33.7	6.6	5.7	46.2	92.4	40%

Table 5.20
Swine and Dairy Operation in Ridge and Valley Region
Effect of Slope on Simulated Phosphorus Losses and Reduction Efficiency
Dairy Manure

	Phosphorus Losses Before Nutrient Management (lb/ac)				Phosphorus Losses After Nutrient Management (lb/ac)				
Slope	Erosion	Runoff	Percolation	Total	Erosion	Runoff	Percolation	Total	Reduction Efficiency
%2	1.2	0.6	0.2	2.0	1.0	0.3	0.2	1.4	27%
%5	2.7	0.7	0.2	3.5	2.1	0.3	0.2	2.5	29%
%10	6.0	0.8	0.2	7.0	4.6	0.3	0.2	5.0	28%

Table 5.21
Swine and Dairy Operation in Ridge and Valley Region
Effect of Slope on Simulated Nitrogen Losses and Reduction Efficiency
Hog Manure

	Nitrogen Losses Before Nutrient Management (lb/ac)					Nitrogen Losses After Nutrient Management (lb/ac)					
Slope	Erosion	Runoff	Lateral Flow	Percolation	Total	Erosion	Runoff	Lateral Flow	Percolation	Total	Reduction Efficiency
%2	9.4	8.4	3.7	204.9	226.4	6.9	4.0	1.2	71.5	83.5	63%
%5	20.4	10.8	9.5	191.8	232.5	14.7	5.1	3.6	65.0	88.3	62%
%10	46.1	13.8	18.1	170.9	248.9	32.5	6.6	6.8	55.1	100.9	59%

Table 5.22
Swine and Dairy Operation in Ridge And Valley Region
Effect of Slope on Simulated Phosphorus Losses and Reduction Efficiency
Hog Manure

	Phosphorus Losses Before Nutrient Management (lb/ac)				Phosphorus Losses After Nutrient Management (lb/ac)				
Slope	Erosion	Runoff	Percolation	Total	Erosion	Runoff	Percolation	Total	Reduction Efficiency
%2	2.9	2.5	0.2	5.5	1.7	1.2	0.2	3.0	45%
%5	6.2	2.9	0.2	9.3	3.8	1.3	0.2	5.3	43%
%10	14.4	3.3	0.2	17.8	8.5	1.5	0.2	10.2	43%

Table 5.23
Swine and Dairy Operation in Ridge and Valley Region
Effect of Soil Type on Simulated Hydrology

Soil	Hydrologic Group	Slope	Runoff (in/ac)	Lateral Flow (in/ac)	Percolation (in/ac)	Erosion (t/ac)
Calvin-Leck Kill shaly silt loam	C	5%	5.0	0.8	11.7	0.9
Berks shaly silt loam	C	5%	4.8	0.8	11.8	1.1
Dekalb channery sandy loam	C	5%	4.6	0.9	14.6	0.8

Table 5.24
Swine and Dairy Operation in Ridge and Valley Region
Effect of Soil Type on Simulated Nitrogen Losses and Reduction Efficiency

	Nitrogen Losses Before Nutrient Management (lb/ac)					Nitrogen Losses After Nutrient Management (lb/ac)					
Soil /Manure	Erosion	Runoff	Lateral Flow	Percolation	Total	Erosion	Runoff	Lateral Flow	Percolation	Total	Reduction Efficiency
Calvin/Dairy	17.8	7.8	5.4	106.0	137.1	15.3	5.1	2.9	55.0	78.4	43%
Calvin/Hog	20.4	10.8	9.5	191.8	232.5	14.7	5.1	3.6	65.0	88.3	62%
Berks/Dairy	17.8	7.6	5.3	107.1	137.8	15.1	4.9	2.8	55.9	78.6	43%
Berks/Hog	20.4	10.3	8.9	184.8	224.5	14.7	4.7	3.2	63.1	85.8	62%
Dekalb/Dairy	12.7	6.2	6.2	124.1	149.2	10.6	4.0	3.6	68.1	86.4	42%
Dekalb/Hog	14.5	8.9	10.6	217.8	252.0	10.2	4.2	4.3	81.1	99.9	60%

Table 5.25
Swine and Dairy Operation in Ridge and Valley Region
Effect of Soil on Simulated Phosphorus Losses and Reduction Efficiency

	Phosphorus Losses Before Nutrient Management (lb/ac)				Phosphorus Losses After Nutrient Management (lb/ac)				
Soil	Erosion	Runoff	Percolation	Total	Erosion	Runoff	Percolation	Total	Reduction Efficiency
Calvin/Dairy	2.7	0.7	0.2	3.5	2.1	0.3	0.2	2.5	29%
Calvin/Hog	6.2	2.9	0.2	9.3	3.8	1.3	0.2	5.3	43%
Berks/Dairy	2.9	0.6	0.2	3.7	2.2	0.3	0.2	2.7	27%
Berks/Hog	6.9	2.7	0.2	9.8	4.2	1.2	0.2	5.5	44%
Dekalb/Dairy	2.0	0.5	0.2	2.7	1.5	0.2	0.2	2.0	27%
Dekalb/Hog	4.6	2.4	0.3	7.3	2.8	1.1	0.2	4.0	45%

Table 6.1
Dairy Operation in Piedmont Region
Lancaster County, PA
Hagerstown silt loam 3-8% slope
Silage Corn Rotation Before Nutrient Management

	Year 1	
Jan 15	Manure	10-4-8 lbs/ton @ 35 tons/ac
Apr 10	Manure	10-4-8 lbs/ton @ 35 tons/ac
Apr 20	Conventional tillage	
Apr 25	Plant corn	
Apr 25	Fertilize	70 lbs. N
Sept 15	Harvest	
Nov 5	Manure	10-4-8 lbs/ton @ 35 tons/ac
	Year 2	
Feb 5	Manure	10-4-8 lbs/ton @ 28 tons/ac
Apr 20	Conventional tillage	
Apr 25	Plant Corn	
Apr 25	Fertilize	70 lbs. N
Sept 25	Harvest	
Nov 5	Manure	10-4-8 lbs/ton @ 35 tons/ac
	Year 3	
Feb 5	Manure	10-4-8 lbs/ton @ 28 tons/ac
Apr 20	Conventional tillage	
Apr 25	Plant Corn	
Apr 25	Fertilize	70 lbs. N
Sept 25	Harvest	
Nov 5	Manure	10-4-8 lbs/ton @ 35 tons/ac
	Year 4	

Table 6.1
Dairy Operation in Piedmont Region
Lancaster County, PA
Hagerstown silt loam 3-8% slope
Silage Corn Rotation Before Nutrient Management

Feb 5	Manure	10-4-8 lbs/ton @ 28 tons/ac
Apr 20	Conventional tillage	
Apr 25	Plant Corn	
Apr 25	Fertilize	70 lbs. N
Sept 25	Harvest	
Nov 5	Manure	10-4-8 lbs/ton @ 35 tons/ac
	Year 5	
Aug 10	Conventional tillage	
Aug 15	Plant Alfalfa	
	Year 6	
May 15	Cut alfalfa	
June 25	Cut alfalfa	
Aug 5	Cut alfalfa	
Sept 15	Cut alfalfa	
	Year 7	
May 15	Cut alfalfa	
June 25	Cut alfalfa	
Aug 5	Cut alfalfa	
Sept 15	Cut alfalfa	
	Year 8	
May 15	Cut alfalfa	
June 25	Cut alfalfa	
Aug 5	Cut alfalfa	
Sept 15	Cut alfalfa	

Table 6.2
Dairy Operation in Piedmont Region
Average Annual Hydrology and Nutrient Losses
Silage Corn Rotation Before Nutrient Management

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	39.2	6.5	59.3	27.3
Runoff (in/ac)	4.4	3.2	12.9	0.1
Lateral Flow (in/ac)	0.7	0.2	1.5	0.4
Percolation (in/ac)	8.8	3.9	21.7	0.7
Evapotranspiration (in/ac)	25.3	2.7	29.9	17.0
Erosion (t/ac)	4.0	4.0	23.4	0.1
P Losses in Erosion (lb/ac)	9.7	9.2	44.8	0.2
P Losses in Runoff (lb/ac)	1.0	1.1	3.6	0.0
P Losses in Percolation (lb/ac)	0.1	0.0	0.2	0.0
N Losses in Erosion (lb/ac)	68.1	65.8	350.6	1.7
N Losses in Runoff (lb/ac)	16.2	15.4	53.5	0.0
N Losses in Lateral Flow (lb/ac)	5.7	3.0	11.6	0.9
N Losses in Percolation (lb/ac)	89.3	65.6	366.8	7.1
Denitrification (lb/ac)	8.0	4.7	25.3	1.2
Ammonia Volatilization (lb/ac)	49.3	50.6	140.2	0.0
Nitrogen Fixation (lb/ac)	83.8	95.6	175.1	0.0
Nitrogen in Corn Yield (lb/ac)	209.3	15.4	231.1	150.8
Nitrogen in Alfalfa Yield (lb/ac)	248.3	26.1	328.4	201.7
Fertilizer Nitrogen (lb/ac)	402.5			

Table 6.3
Dairy Operation in Piedmont Region
Average Annual Hydrology and Erosion For Rotation Years
Silage Corn Rotation Before Nutrient Management

Rotation Year	Runoff (in/ac)	Lateral Flow (in/ac)	Percolation (in/ac)	Erosion (t/ac)
Year 1	4.7	0.7	9.1	3.4
Year 2	5.9	0.6	5.9	7.1
Year 3	7.3	0.7	8.0	6.8
Year 4	6.6	0.6	6.5	6.7
Year 5	6.2	0.7	10.9	6.6
Year 6	1.1	0.8	10.2	0.7
Year 7	2.1	0.8	11.1	0.5
Year 8	1.2	0.7	9.1	0.7

Table 6.4
Dairy Operation in Piedmont Region
Average Annual Nitrogen Losses For Rotation Years
Silage Corn Rotation Before Nutrient Management

	Nitrogen Losses (lb/ac)				
Rotation Year	**Erosion**	**Runoff**	**Lateral Flow**	**Percolation**	**Total**
Year 1	61.7	27.7	8.0	41.6	138.9
Year 2	114.3	26.4	7.6	39.2	187.5
Year 3	114.6	30.3	8.0	90.7	243.5
Year 4	113.2	29.9	7.9	79.3	230.3
Year 5	110.6	14.3	7.1	160.7	292.7
Year 6	11.4	0.1	3.5	143.9	158.9
Year 7	6.8	0.4	1.9	105.3	114.3
Year 8	12.0	0.1	1.4	53.6	67.1
Average	68.1	16.2	5.7	89.3	179.2

Table 6.5
Dairy Operation in Piedmont Region
Average Annual Phosphorus Losses For Rotation Years
Silage Corn Rotation Before Nutrient Management

	Phosphorus Losses (lb/ac)			
Rotation Year	**Erosion**	**Runoff**	**Percolation**	**Total**
Year 1	8.9	0.8	0.1	9.8
Year 2	16.4	1.6	0.1	18.1
Year 3	16.8	2.1	0.1	18.9
Year 4	17.0	1.8	0.0	18.9
Year 5	15.7	1.6	0.1	17.4
Year 6	1.2	0.0	0.1	1.3
Year 7	0.7	0.1	0.1	0.9
Year 8	1.2	0.0	0.1	1.3
Average	9.7	1.0	0.1	10.8

Table 6.6
Dairy Operation in Piedmont Region
Lancaster County, PA
Hagerstown silt loam 3-8% slope
Silage Corn Rotation After Nutrient Management

	Year 1	
Apr 20	Manure	10-4-8 lbs/ton @ 24 tons/ac
Apr 24	Conventional tillage	
Apr 25	Plant corn	
Apr 25	Fertilize	36 lbs. N
Sept 15	Harvest	
	Year 2	
Apr 20	Manure	10-4-8 lbs/ton @ 16 tons/ac
Apr 24	Conventional tillage	
Apr 25	Plant Corn	
Apr 25	Fertilize	39 lbs. N 65 lbs. P2O5
Sept 25	Harvest	
	Year 3	
Apr 20	Manure	10-4-8 lbs/ton @ 16 tons/ac
Apr 24	Conventional tillage	
Apr 25	Plant Corn	
Apr 25	Fertilize	39 lbs. N 65 lbs. P2O5
Sept 25	Harvest	
	Year 4	
Apr 20	Manure	10-4-8 lbs/ton @ 16 tons/ac
Apr 24	Conventional tillage	
Apr 25	Plant Corn	
Apr 25	Fertilize	39 lbs. N 65 lbs. P2O5

Table 6.6
Dairy Operation in Piedmont Region
Lancaster County, PA
Hagerstown silt loam 3-8% slope
Silage Corn Rotation After Nutrient Management

Sept 25	Harvest	
	Year 5	
Aug 10	Conventional tillage	
Aug 12	Fertilize	70 lbs. P2O5
Aug 15	Plant Alfalfa	
	Year 6	
May 15	Cut alfalfa	
June 25	Cut alfalfa	
Aug 5	Cut alfalfa	
Aug 10	Fertilize	10 lbs. N 20 lbs. P2O5
Sept 15	Cut alfalfa	
	Year 7	
May 15	Cut alfalfa	
June 25	Cut alfalfa	
Aug 5	Cut alfalfa	
Aug 10	Fertilize	10 lbs. N 20 lbs. P2O5
Sept 15	Cut alfalfa	
	Year 8	
May 15	Cut alfalfa	
June 25	Cut alfalfa	
Aug 5	Cut alfalfa	
Aug 10	Fertilize	10 lbs. N 20 lbs. P2O5
Sept 15	Cut alfalfa	
Nov 15	Manure	10-4-8 lbs/ton @ 24 tons/ac

Table 6.7
Dairy Operation in Piedmont Region
Average Annual Hydrology and Nutrient Losses
Silage Corn Rotation After Nutrient Management

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	39.2	6.5	59.3	27.3
Runoff (in/ac)	5.3	2.9	14.7	0.5
Lateral Flow (in/ac)	0.6	0.2	1.1	0.4
Percolation (in/ac)	8.2	3.4	16.7	0.7
Evapotranspiration (in/ac)	25.1	2.7	29.9	16.9
Erosion (t/ac)	3.8	3.7	22.0	0.1
P Losses in Erosion (lb/ac)	6.0	5.4	28.0	0.1
P Losses in Runoff (lb/ac)	0.3	0.4	1.8	0.0
P Losses in Percolation (lb/ac)	0.1	0.0	0.1	0.0
N Losses in Erosion (lb/ac)	30.1	28.6	165.1	0.5
N Losses in Runoff (lb/ac)	6.5	5.2	23.2	0.0
N Losses in Lateral Flow (lb/ac)	1.6	0.9	4.5	0.0
N Losses in Percolation (lb/ac)	6.1	6.0	24.1	0.0
Denitrification (lb/ac)	1.4	0.7	2.8	0.3
Ammonia Volatilization (lb/ac)	14.5	14.6	58.6	0.0
Nitrogen Fixation (lb/ac)	65.7	76.8	156.3	0.0
Nitrogen in Corn Yield (lb/ac)	150.9	33.6	215.1	108.0
Nitrogen in Alfalfa Yield (lb/ac)	194.4	22.0	241.8	154.4
Fertilizer Nitrogen (lb/ac)	142.9			

Table 6.8
Dairy Operation in Piedmont Region
Average Annual Nitrogen Losses For Rotation Years
Silage Corn Rotation After Nutrient Management

	Nitrogen Losses (lb/ac)				
Rotation Year	**Erosion**	**Runoff**	**Lateral Flow**	**Percolation**	**Total**
Year 1	34.3	12.6	3.2	5.4	55.4
Year 2	52.1	6.8	1.7	4.0	64.6
Year 3	52.7	10.1	1.7	4.0	68.5
Year 4	46.9	7.9	1.3	2.1	58.4
Year 5	40.2	7.2	1.3	7.6	56.3
Year 6	6.0	0.7	1.2	15.6	23.5
Year 7	3.1	2.3	0.9	6.3	12.7
Year 8	5.5	4.5	1.4	3.4	14.8
Average	30.1	6.5	1.6	6.1	44.3

Table 6.9
Dairy Operation in Piedmont Region
Average Annual Phosphorus Losses For Rotation Years
Silage Corn Rotation After Nutrient Management

	Phosphorus Losses (lb/ac)			
Rotation Year	**Erosion**	**Runoff**	**Percolation**	**Total**
Year 1	5.5	0.4	0.1	6.0
Year 2	9.3	0.3	0.1	9.6
Year 3	10.7	0.4	0.1	11.2
Year 4	10.1	0.3	0.0	10.4
Year 5	8.7	0.4	0.1	9.2
Year 6	1.8	0.1	0.1	2.0
Year 7	0.7	0.3	0.1	1.1
Year 8	0.9	0.0	0.0	0.9
Average	6.0	0.3	0.1	6.3

Table 6.10
Dairy Operation in Piedmont Region
Lancaster County, PA
Hagerstown silt loam 3-8% slope
Grain Corn Rotation Before Nutrient Management

	Year 1	
Mar 15	Manure	10-4-8 lbs/ton @ 19 tons/ac
June 1	Conventional tillage	
June 5	Plant corn	
June 10	Fertilize	50 lbs. N
Oct 25	Harvest	
	Year 2	
Jan 25	Manure	10-4-8 lbs/ton @ 19 tons/ac
May 1	Manure	10-4-8 lbs/ton @ 31 tons/ac
May 3	Conventional tillage	
May 5	Plant Corn	
May 7	Fertilize	90 lbs. N
Oct 15	Harvest	
	Year 3	
Jan 25	Manure	10-4-8 lbs/ton @ 19 tons/ac
May 1	Manure	10-4-8 lbs/ton @ 31 tons/ac
May 3	Conventional tillage	
May 5	Plant Corn	
May 7	Fertilize	90 lbs. N
Oct 15	Harvest	
	Year 4	
Jan 25	Manure	10-4-8 lbs/ton @ 19 tons/ac
May 1	Manure	10-4-8 lbs/ton @ 31 tons/ac

Table 6.10
Dairy Operation in Piedmont Region
Lancaster County, PA
Hagerstown silt loam 3-8% slope
Grain Corn Rotation Before Nutrient Management

May 3	Conventional tillage	
May 5	Plant Corn	
May 7	Fertilize	90 lbs. N
Oct 15	Harvest	
	Year 5	
Aug 10	Conventional tillage	
Aug 15	Plant Alfalfa	
	Year 6	
May 15	Cut alfalfa	
June 25	Cut alfalfa	
Aug 5	Cut alfalfa	
Sept 15	Cut alfalfa	
	Year 7	
May 15	Cut alfalfa	
June 25	Cut alfalfa	
Aug 5	Cut alfalfa	
Sept 15	Cut alfalfa	
	Year 8	
May 15	Cut alfalfa	
June 25	Cut alfalfa	
Aug 5	Cut alfalfa	
Sept 15	Cut alfalfa	
Dec 10	Manure	10-4-8 lbs/ton @ 19 tons/ac

Table 6.11
Dairy Operation in Piedmont Region
Average Annual Hydrology and Nutrient Losses
Grain Corn Rotation Before Nutrient Management

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	39.2	6.5	59.3	27.3
Runoff (in/ac)	4.3	3.2	12.4	0.1
Lateral Flow (in/ac)	0.7	0.2	1.5	0.4
Percolation (in/ac)	9.0	3.9	21.6	0.4
Evapotranspiration (in/ac)	25.1	2.6	30.0	17.0
Erosion (t/ac)	2.4	2.8	16.9	0.1
P Losses in Erosion (lb/ac)	4.8	5.8	28.2	0.2
P Losses in Runoff (lb/ac)	0.4	0.6	1.8	0.0
P Losses in Percolation (lb/ac)	0.1	0.0	0.1	0.0
N Losses in Erosion (lb/ac)	32.7	38.3	206.1	1.2
N Losses in Runoff (lb/ac)	14.5	15.8	51.8	0.0
N Losses in Lateral Flow (lb/ac)	5.4	3.1	11.6	0.9
N Losses in Percolation (lb/ac)	88.6	69.9	365.9	5.4
Denitrification (lb/ac)	8.3	5.0	24.5	0.8
Ammonia Volatilization (lb/ac)	29.4	29.4	64.8	0.0
Nitrogen Fixation (lb/ac)	88.6	94.0	176.4	0.0
Nitrogen in Corn Yield (lb/ac)	130.6	9.0	146.3	108.9
Nitrogen in Alfalfa Yield (lb/ac)	205.7	96.5	328.4	0.9
Fertilizer Nitrogen (lb/ac)	275			

Table 6.12
Dairy Operation in Piedmont Region
Average Annual Hydrology and Erosion For Rotation Years
Grain Corn Rotation Before Nutrient Management

Rotation Year	Runoff (in/ac)	Lateral Flow (in/ac)	Percolation (in/ac)	Erosion (t/ac)
Year 1	4.5	0.7	9.6	0.2
Year 2	5.9	0.6	7.2	4.2
Year 3	7.4	0.7	8.1	4.7
Year 4	6.7	0.6	6.3	5.0
Year 5	6.0	0.7	11.0	3.1
Year 6	1.1	0.8	10.2	0.7
Year 7	2.0	0.8	11.2	0.4
Year 8	1.1	0.7	9.2	0.6

Table 6.13
Dairy Operation in Piedmont Region
Average Annual Nitrogen Losses For Rotation Years
Grain Corn Rotation Before Nutrient Management

	Nitrogen Losses (lb/ac)				
Rotation Year	**Erosion**	**Runoff**	**Lateral Flow**	**Percolation**	**Total**
Year 1	4.6	6.5	7.1	23.0	41.2
Year 2	53.2	23.9	7.7	40.7	125.5
Year 3	68.6	38.8	7.7	94.4	209.5
Year 4	74.2	30.2	7.4	88.9	200.6
Year 5	38.5	15.9	6.8	177.0	238.2
Year 6	9.3	0.1	3.1	148.0	160.5
Year 7	5.2	0.3	1.4	96.4	103.2
Year 8	7.8	0.8	1.3	40.4	50.3
Average	32.7	14.5	5.4	88.6	141.1

Table 6.14
Dairy Operation in Piedmont Region
Average Annual Phosphorus Losses For Rotation Years
Grain Corn Rotation Before Nutrient Management

	Phosphorus Losses (lb/ac)			
Rotation Year	**Erosion**	**Runoff**	**Percolation**	**Total**
Year 1	0.6	0.1	0.1	0.8
Year 2	7.8	0.7	0.1	8.6
Year 3	10.8	1.2	0.1	12.1
Year 4	12.0	1.2	0.0	13.3
Year 5	5.3	0.5	0.1	5.9
Year 6	1.1	0.0	0.1	1.2
Year 7	0.5	0.1	0.1	0.7
Year 8	0.8	0.0	0.1	0.9
Average	4.8	0.4	0.1	5.4

Table 6.15
Dairy Operation in Piedmont Region
Lancaster County, PA
Hagerstown silt loam 3-8% slope
Grain Corn Rotation After Nutrient Management

	Year 1	
Mar 15	Manure	10-4-8 lbs/ton @ 16 tons/ac
June 1	Manure	10-4-8 lbs/ton @ 25 tons/ac
June 2	Conventional tillage	
June 5	Plant corn	
July 10	Fertilize	57 lbs. N
Oct 25	Harvest	
	Year 2	
May 1	Manure	10-4-8 lbs/ton @ 16 tons/ac
May 2	Conventional tillage	
May 5	Plant Corn	
June 5	Fertilize	85 lbs. N
Oct 15	Harvest	
	Year 3	
May 1	Manure	10-4-8 lbs/ton @ 16 tons/ac
May 2	Conventional tillage	
May 5	Plant Corn	
June 5	Fertilize	85 lbs. N
Oct 15	Harvest	
	Year 4	
May 1	Manure	10-4-8 lbs/ton @ 16 tons/ac
May 2	Conventional tillage	
May 5	Plant Corn	

Table 6.15
Dairy Operation in Piedmont Region
Lancaster County, PA
Hagerstown silt loam 3-8% slope
Grain Corn Rotation After Nutrient Management

June 5	Fertilize	85 lbs. N
Oct 15	Harvest	
	Year 5	
Aug 10	Conventional tillage	
Aug 12	Fertilize	70 lbs. P2O5
Aug 15	Plant Alfalfa	
	Year 6	
May 15	Cut alfalfa	
June 25	Cut alfalfa	
Aug 5	Cut alfalfa	
Aug 10	Fertilize	10 lbs. N 20 lbs. P2O5
Sept 15	Cut alfalfa	
	Year 7	
May 15	Cut alfalfa	
June 25	Cut alfalfa	
Aug 5	Cut alfalfa	
Aug 10	Fertilize	10 lbs. N 20 lbs. P2O5
Sept 15	Cut alfalfa	
	Year 8	
May 15	Cut alfalfa	
June 25	Cut alfalfa	
Aug 5	Cut alfalfa	
Aug 10	Fertilize	10 lbs. N 20 lbs. P2O5
Sept 15	Cut alfalfa	

Table 6.16
Dairy Operation in Piedmont Region
Average Annual Hydrology and Nutrient Losses
Grain Corn Rotation After Nutrient Management

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	39.2	6.5	59.3	27.3
Runoff (in/ac)	4.2	3.2	12.6	0.1
Lateral Flow (in/ac)	0.7	0.2	1.5	0.4
Percolation (in/ac)	8.7	4.0	21.6	0.4
Evapotranspiration (in/ac)	25.6	3.0	31.8	17.0
Erosion (t/ac)	2.9	2.9	18.6	0.1
P Losses in Erosion (lb/ac)	2.5	2.1	10.3	0.1
P Losses in Runoff (lb/ac)	0.0	0.0	0.0	0.0
P Losses in Percolation (lb/ac)	0.1	0.0	0.1	0.0
N Losses in Erosion (lb/ac)	26.7	26.8	157.9	1.0
N Losses in Runoff (lb/ac)	8.8	8.6	30.3	0.0
N Losses in Lateral Flow (lb/ac)	2.5	1.5	6.2	0.0
N Losses in Percolation (lb/ac)	27.4	27.8	139.2	0.0
Denitrification (lb/ac)	3.0	1.9	9.9	0.2
Ammonia Volatilization (lb/ac)	12.7	16.0	50.9	0.0
Nitrogen Fixation (lb/ac)	97.2	99.6	187.7	0.0
Nitrogen in Corn Yield (lb/ac)	127.2	13.8	146.3	66.0
Nitrogen in Alfalfa Yield (lb/ac)	247.8	26.1	326.6	201.7
Fertilizer Nitrogen (lb/ac)	154			

Table 6.17
Dairy Operation in Piedmont Region
Average Annual Nitrogen Losses For Rotation Years
Grain Corn Rotation After Nutrient Management

	Nitrogen Losses (lb/ac)				
Rotation Year	**Erosion**	**Runoff**	**Lateral Flow**	**Percolation**	**Total**
Year 1	33.1	7.5	3.4	1.2	45.2
Year 2	45.7	15.6	3.1	13.4	77.8
Year 3	47.3	17.2	3.2	34.3	102.0
Year 4	46.4	15.7	3.2	24.0	89.3
Year 5	25.1	14.4	3.9	50.7	94.1
Year 6	5.9	0.3	1.9	56.9	65.0
Year 7	3.7	0.3	0.7	31.2	35.9
Year 8	6.6	0.1	0.5	7.5	14.7
Average	26.7	8.8	2.5	27.4	65.5

Table 6.18
Dairy Operation in Piedmont Region
Average Annual Phosphorus Losses For Rotation Years
Grain Corn Rotation After Nutrient Management

	Phosphorus Losses (lb/ac)			
Rotation Year	**Erosion**	**Runoff**	**Percolation**	**Total**
Year 1	3.2	0.0	0.1	3.3
Year 2	3.9	0.0	0.1	4.0
Year 3	4.2	0.0	0.1	4.3
Year 4	4.4	0.0	0.0	4.4
Year 5	2.8	0.0	0.1	2.9
Year 6	0.7	0.0	0.1	0.8
Year 7	0.4	0.0	0.1	0.4
Year 8	0.6	0.0	0.1	0.7
Average	2.5	0.0	0.1	2.6

Table 6.19
Dairy Operation in Piedmont Region
Sensitivity of Nitrogen Losses and Reduction Efficiency to the Percent of the Organic Nitrogen Available in First Year Represented As Nitrate
Silage Corn

	Nitrogen Losses Before Nutrient Management (lb/ac)					Nitrogen Losses After Nutrient Management (lb/ac)					
% Available 1st Year Nitrogen	Erosion	Runoff	Lateral Flow	Percolation	Total	Erosion	Runoff	Lateral Flow	Percolation	Total	Reduction Efficiency
0%	79.2	10.4	4.7	75.1	169.4	33.3	5.6	1.4	7.1	47.4	72%
50%	68.1	16.2	5.7	89.3	179.2	30.1	6.5	1.6	6.1	44.3	75%
75%	63.3	18.8	6.2	97.7	186.1	28.8	7.0	1.6	6.2	43.5	77%
100%	56.9	22.0	7.0	107.3	193.3	27.0	7.4	1.8	6.8	43.0	78%

Table 6.20
Dairy Operation in Piedmont Region
Sensitivity of Nitrogen Losses and Reduction Efficiency to the Percent of the Organic Nitrogen Available in First Year Represented As Nitrate
Grain Corn

	Nitrogen Losses Before Nutrient Management (lb/ac)					Nitrogen Losses After Nutrient Management (lb/ac)					
% Available 1st Year Nitrogen	Erosion	Runoff	Lateral Flow	Percolation	Total	Erosion	Runoff	Lateral Flow	Percolation	Total	Reduction Efficiency
0%	37.1	10.4	4.8	80.8	133.2	29.1	8.0	2.2	22.0	61.3	54%
50%	32.7	14.5	5.4	88.6	141.1	26.7	8.8	2.5	27.4	65.5	54%
75%	30.7	16.5	5.6	93.3	146.1	25.7	9.3	2.6	30.5	68.2	53%
100%	28.1	18.9	6.0	98.5	151.5	24.4	9.6	2.8	34.5	71.3	53%

Table 6.21
Dairy Operation in Piedmont Region
Effect of Slope on Simulated Hydrology
Silage Corn

Slope	Runoff (in/ac)	Lateral Flow (in/ac)	Percolation (in/ac)	Erosion (t/ac)
%2	3.8	0.3	9.9	1.6
%5	4.4	0.7	8.8	4.0
%10	5.2	1.3	7.2	10.3

Table 6.22
Dairy Operation in Piedmont Region
Effect of Slope on Simulated Nitrogen Losses and Reduction Efficiency
Silage Corn

	Nitrogen Losses Before Nutrient Management (lb/ac)					Nitrogen Losses After Nutrient Management (lb/ac)					
Slope	Erosion	Runoff	Lateral Flow	Percolation	Total	Erosion	Runoff	Lateral Flow	Percolation	Total	Reduction Efficiency
%2	32.4	13.0	2.3	107.3	155.0	14.3	5.0	0.4	8.7	28.5	82%
%5	68.1	16.2	5.7	89.3	179.2	30.1	6.5	1.6	6.1	44.3	75%
%10	132.9	19.9	9.5	57.7	220.0	60.1	8.1	2.9	3.1	74.2	66%

Table 6.23
Dairy Operation in Piedmont Region
Effect of Slope on Simulated Phosphorus Losses and Reduction Efficiency
Silage Corn

	Phosphorus Losses Before Nutrient Management (lb/ac)				Phosphorus Losses After Nutrient Management (lb/ac)				
Slope	Erosion	Runoff	Percolation	Total	Erosion	Runoff	Percolation	Total	Reduction Efficiency
%2	4.6	0.9	0.1	5.5	2.9	0.3	0.1	3.3	40%
%5	9.7	1.0	0.1	10.8	6.0	0.3	0.1	6.3	42%
%10	19.9	1.0	0.0	20.9	11.3	0.2	0.0	11.5	45%

Table 6.24
Dairy Operation in Piedmont Region
Effect of Slope on Simulated Hydrology
Grain Corn

Slope	Runoff (in/ac)	Lateral Flow (in/ac)	Percolation (in/ac)	Erosion (t/ac)
%2	3.8	0.3	10.2	0.9
%5	4.3	0.7	9.0	2.4
%10	5.1	1.3	7.5	5.9

Table 6.25
Dairy Operation in Piedmont Region
Effect of Slope on Simulated Nitrogen Losses and Reduction Efficiency
Grain Corn

	Nitrogen Losses Before Nutrient Management (lb/ac)					Nitrogen Losses After Nutrient Management (lb/ac)					
Slope	Erosion	Runoff	Lateral Flow	Percolation	Total	Erosion	Runoff	Lateral Flow	Percolation	Total	Reduction Efficiency
%2	15.3	11.7	2.0	101.2	130.1	12.0	7.0	0.9	34.0	53.8	59%
%5	32.7	14.5	5.4	88.6	141.1	26.7	8.8	2.5	27.4	65.5	54%
%10	67.9	18.5	9.6	69.1	165.1	55.1	11.6	4.6	17.0	88.2	47%

Table 6.26
Dairy Operation in Piedmont Region
Effect of Slope on Simulated Phosphorus Losses and Reduction Efficiency
Grain Corn

	Phosphorus Losses Before Nutrient Management (lb/ac)				Phosphorus Losses After Nutrient Management (lb/ac)				
Slope	Erosion	Runoff	Percolation	Total	Erosion	Runoff	Percolation	Total	Reduction Efficiency
%2	2.2	0.4	0.1	2.8	1.2	0.0	0.1	1.2	58%
%5	4.8	0.4	0.1	5.4	2.5	0.0	0.1	2.6	52%
%10	10.0	0.4	0.0	10.4	5.2	0.0	0.0	5.3	50%

Table 6.27
Dairy Operation in Piedmont Region
Effect of Soil Type on Simulated Hydrology
Silage Corn

Soil	Hydrologic Group	Slope	Runoff (in/ac)	Lateral Flow (in/ac)	Percolation (in/ac)	Erosion (t/ac)
Hagerstown silt loam	B	5%	4.4	0.7	8.8	4.0
Manor silt loam	B	5%	3.8	0.7	10.2	4.5
Conestoga silt loam	B	5%	4.1	0.7	8.9	4.6

Table 6.28
Dairy Operation in Piedmont Region
Effect of Soil Type on Simulated Nitrogen Losses and Reduction Efficiency
Silage Corn

	Nitrogen Losses Before Nutrient Management (lb/ac)					Nitrogen Losses After Nutrient Management (lb/ac)					
Soil	Erosion	Runoff	Lateral Flow	Percolation	Total	Erosion	Runoff	Lateral Flow	Percolation	Total	Reduction Efficiency
Hagerstown silt loam	68.1	16.2	5.7	89.3	179.2	30.1	6.5	1.6	6.1	44.3	75%
Manor silt loam	63.4	13.0	5.4	95.3	177.1	26.1	4.9	1.5	11.3	44.0	75%
Conestoga silt loam	65.0	15.6	5.8	100.3	186.7	26.9	6.2	1.6	10.0	44.8	76%

Table 6.29
Dairy Operation in Piedmont Region
Effect of Soil on Simulated Phosphorus Losses and Reduction Efficiency
Silage Corn

	Phosphorus Losses Before Nutrient Management (lb/ac)				Phosphorus Losses After Nutrient Management (lb/ac)				
Soil	Erosion	Runoff	Percolation	Total	Erosion	Runoff	Percolation	Total	Reduction Efficiency
Hagerstown silt loam	9.7	1.0	0.1	10.8	6.0	0.3	0.1	6.3	42%
Manor silt loam	10.0	0.8	0.1	10.8	6.2	0.2	0.1	6.3	41%
Conestoga silt loam	10.0	0.8	0.1	10.9	5.8	0.2	0.1	6.0	45%

Table 6.30
Dairy Operation in Piedmont Region
Effect of Soil Type on Simulated Hydrology
Grain Corn

Soil	Hydrologic Group	Slope	Runoff (in/ac)	Lateral Flow (in/ac)	Percolation (in/ac)	Erosion (t/ac)
Hagerstown silt loam	B	5%	4.3	0.7	9.0	2.4
Manor silt loam	B	5%	3.6	0.7	10.3	2.5
Conestoga silt loam	B	5%	4.1	0.7	9.1	2.6

Table 6.31
Dairy Operation in Piedmont Region
Effect of Soil Type on Simulated Nitrogen Losses and Reduction Efficiency
Grain Corn

	Nitrogen Losses Before Nutrient Management (lb/ac)					Nitrogen Losses After Nutrient Management (lb/ac)					
Soil /Manure	Erosion	Runoff	Lateral Flow	Percolation	Total	Erosion	Runoff	Lateral Flow	Percolation	Total	Reduction Efficiency
Hagerstown silt loam	32.7	14.5	5.4	88.6	141.1	26.7	8.8	2.5	27.4	65.5	54%
Manor silt loam	29.0	10.6	5.2	97.2	142.0	22.8	6.3	2.5	38.4	70.0	51%
Conestoga silt loam	29.4	13.8	5.4	97.9	146.5	22.6	8.3	2.5	34.3	67.6	54%

Table 6.32
Dairy Operation in Piedmont Region
Effect of Soil on Simulated Phosphorus Losses and Reduction Efficiency
Grain Corn

	Phosphorus Losses Before Nutrient Management (lb/ac)				Phosphorus Losses After Nutrient Management (lb/ac)				
Soil	Erosion	Runoff	Percolation	Total	Erosion	Runoff	Percolation	Total	Reduction Efficiency
Hagerstown silt loam	4.8	0.4	0.1	5.4	2.5	0.0	0.1	2.6	52%
Manor silt loam	4.6	0.4	0.1	5.1	2.4	0.0	0.1	2.5	51%
Conestoga silt loam	4.6	0.4	0.1	5.1	2.1	0.0	0.1	2.1	58%

Table 7.1
Poultry Operation in the Coastal Plain
Corn, Double Crop Small Grain Soybean Rotation
Caroline County, MD
Sassafras Sandy Loam 0-2% slope
Before Nutrient Management

	Year 1	
Feb 1	Apply broiler litter	3 tons/acre 60 lbs TKN/ton, 15 lbs NH_4/ton 63 lbs P_2O_5/ton
Apr 25	Plant no-till corn	
Apr 25	Fertilize	20 lbs N/ac-20 lbs. P/ac
Jun 20	Sidedress N	50-60 lbs N/ac
Oct 1	Harvest corn grain	125 bu/ac
Oct 10	Moldboard plow	
Oct 15	Fertilize	15 lb N/ac-30 lb P/ac
Oct 15	Disc or harrow	
Oct 15	Plant barley or wheat	
	Year 2	
Feb 20	Fertilize	40 lb N/ac-30 lbs S/ac
Mar 20	Fertilize	50-60 lbs N/ac
Jun 25	Harvest small grain	
Jun 26	Plant no-till soybeans	
Nov 10	Harvest soybeans	

Table 7.2
Poultry Operation in the Coastal Plain Average Annual Hydrology and Nutrient Losses Before Nutrient Management

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	44.4	7.7	63.8	31.7
Runoff (in/ac)	4.2	2.4	13.3	0.6
Lateral Flow (in/ac)	0.2	0.0	0.3	0.1
Percolation (in/ac)	13.4	5.1	24.1	3.8
Evapotranspiration (in/ac)	26.5	3.0	32.6	20.2
Erosion (t/ac)	0.7	0.6	3.1	0.1
P Losses in Erosion (lb/ac)	1.9	2.1	8.4	0.1
P Losses in Runoff (lb/ac)	0.3	0.5	2.7	0.0
P Losses in Percolation (lb/ac)	0.1	0.0	0.2	0.0
N Losses in Erosion (lb/ac)	6.5	6.5	28.5	0.5
N Losses in Runoff (lb/ac)	7.2	8.9	36.6	0.0
N Losses in Lateral Flow (lb/ac)	0.4	0.4	0.9	0.0
N Losses in Percolation (lb/ac)	29.5	17.1	78.5	0.0
Denitrification (lb/ac)	1.3	0.8	3.0	0.0
Ammonia Volatilization (lb/ac)	17.7	17.7	35.7	0.0
Nitrogen Fixation (lb/ac)	100.7	96.9	0.0	0.0
Nitrogen in Corn Yield (lb/ac)	113.3	19.8	138.3	68.7
Nitrogen in Wheat Yield (lb/ac)	94.1	9.9	114.2	69.6
Nitrogen in Soybean Yield (lb/ac)	133.4	16.3	156.2	102.6
Fertilizer Nitrogen (lb/ac)	177.5			

Table 7.3
Poultry Operation in the Coastal Plain
Average Annual Hydrology and Erosion For Rotation Years
Before Nutrient Management

Rotation Year	Runoff (in/ac)	Lateral Flow (in/ac)	Percolation (in/ac)	Erosion (t/ac)
Year 1	5.2	0.2	15.7	1.1
Year 2	3.4	0.2	11.4	0.3

Table 7.4
Poultry Operation in the Coastal Plain
Average Annual Nitrogen Losses For Rotation Years
Before Nutrient Management

	Nitrogen Losses (lb/ac)				
Rotation Year	**Erosion**	**Runoff**	**Lateral Flow**	**Percolation**	**Total**
Year 1	11.2	11.3	0.8	34.7	58.0
Year 2	2.0	3.1	0.1	24.5	29.6
Average	6.5	7.2	0.4	29.5	43.7

Table 7.5
Cash Grain Operation in the Coastal Plain Average Annual Phosphorus Losses For Rotation Years Before Nutrient Management

	Phosphorus Losses (lb/ac)			
Rotation Year	**Erosion**	**Runoff**	**Percolation**	**Total**
Year 1	3.4	0.5	0.1	4.0
Year 2	0.4	0.0	0.1	0.4
Average	1.9	0.3	0.1	2.2

Table 7.6
Poultry Operation in the Coastal Plain Average Annual Hydrology and Nutrient Losses After Nutrient Management

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	44.4	7.7	63.8	31.7
Runoff (in/ac)	4.3	2.5	13.7	0.6
Lateral Flow (in/ac)	0.2	0.0	0.3	0.1
Percolation (in/ac)	13.4	5.1	24.1	3.8
Evapotranspiration (in/ac)	26.5	3.0	32.6	20.2
Erosion (t/ac)	0.7	0.6	3.1	0.1
P Losses in Erosion (lb/ac)	1.9	2.1	8.6	0.1
P Losses in Runoff (lb/ac)	0.3	0.4	1.8	0.0
P Losses in Percolation (lb/ac)	0.1	0.0	0.2	0.0
N Losses in Erosion (lb/ac)	6.4	6.4	28.4	0.5
N Losses in Runoff (lb/ac)	5.1	5.7	31.2	0.0
N Losses in Lateral Flow (lb/ac)	0.2	0.4	0.9	0.0
N Losses in Percolation (lb/ac)	17.7	13.5	53.5	0.0
Denitrification (lb/ac)	1.0	0.6	2.4	0.0
Ammonia Volatilization (lb/ac)	17.7	17.7	35.7	0.0
Nitrogen Fixation (lb/ac)	102.6	99.1	0.0	0.0
Nitrogen in Corn Yield (lb/ac)	112.9	19.5	136.5	68.7
Nitrogen in Wheat Yield (lb/ac)	93.5	9.8	114.2	69.6
Nitrogen in Soybean Yield (lb/ac)	133.4	16.3	156.2	102.6
Fertilizer Nitrogen (lb/ac)	160			

Table 7.7
Poultry Operation in the Coastal Plain
Average Annual Nitrogen Losses For Rotation Years After Nutrient Management

	Nitrogen Losses (lb/ac)				
Rotation Year	**Erosion**	**Runoff**	**Lateral Flow**	**Percolation**	**Total**
Year 1	11.0	7.3	0.4	20.5	39.2
Year 2	2.0	2.9	0.0	14.9	19.8
Average	6.4	5.1	0.2	17.7	29.5

Table 7.8
Poultry Operation in the Coastal Plain
Average Annual Phosphorus Losses For Rotation Years After Nutrient Management

	Phosphorus Losses (lb/ac)			
Rotation Year	**Erosion**	**Runoff**	**Percolation**	**Total**
Year 1	3.4	0.4	0.1	3.9
Year 2	0.4	0.0	0.1	0.4
Average	1.9	0.3	0.1	2.2

Table 7.9
Poultry Operation in the Coastal Plain
Sensitivity of Nitrogen Losses and Reduction Efficiency to the Percent of the Organic Nitrogen Available in First Year Represented As Nitrate

	Nitrogen Losses Before Nutrient Management (lb/ac)					Nitrogen Losses After Nutrient Management (lb/ac)					
% Available 1st Year Nitrogen	Erosion	Runoff	Lateral Flow	Percolation	Total	Erosion	Runoff	Lateral Flow	Percolation	Total	Reduction Efficiency
0%	7.3	4.3	0.3	25.1	36.9	7.3	4.5	0.2	21.5	33.5	9%
50%	6.5	7.2	0.4	29.5	43.7	6.4	5.1	0.2	17.7	29.5	33%
75%	6.2	8.7	0.4	32.3	47.5	6.1	5.6	0.4	18.6	30.6	36%
100%	5.7	10.1	0.4	35.3	51.6	5.7	6.1	0.4	21.3	33.5	35%

Table 7.10
Poultry Operation in the Coastal Plain
Effect of Slope on Simulated Hydrology

Slope	Runoff (in/ac)	Lateral Flow (in/ac)	Percolation (in/ac)	Erosion (t/ac)
%1	4.3	0.2	13.4	0.7
%5	5.4	0.9	11.2	2.2
%8	5.9	1.3	10.1	3.8

Table 7.11
Poultry Operation in the Coastal Plain
Effect of Slope on Simulated Nitrogen Losses and Reduction Efficiency

	Nitrogen Losses Before Nutrient Management (lb/ac)					Nitrogen Losses After Nutrient Management (lb/ac)					
Slope	Erosion	Runoff	Lateral Flow	Percolation	Total	Erosion	Runoff	Lateral Flow	Percolation	Total	Reduction Efficiency
%1	6.5	7.2	0.4	29.5	43.7	6.4	5.1	0.2	17.7	29.5	33%
%5	16.0	10.1	3.4	21.9	51.3	15.8	7.5	2.5	11.2	37.0	28%
%8	26.1	11.6	5.0	17.0	59.5	25.8	8.7	4.0	9.0	47.6	20%

Table 7.12
Poultry Operation in the Coastal Plain
Effect of Slope on Simulated Phosphorus Losses and Reduction Efficiency

	Phosphorus Losses Before Nutrient Management (lb/ac)				Phosphorus Losses After Nutrient Management (lb/ac)				
Slope	Erosion	Runoff	Percolation	Total	Erosion	Runoff	Percolation	Total	Reduction Efficiency
%1	1.9	0.3	0.1	2.2	1.9	0.3	0.1	2.2	0%
%5	4.5	0.3	0.1	4.9	4.6	0.3	0.1	4.9	0%
%8	7.1	0.4	0.1	7.7	7.2	0.3	0.1	7.6	1%

Table 8.2
Cash Grain Operation in the Coastal Plain
Average Annual Hydrology and Nutrient Losses
Inorganic Fertilizer

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	44.4	7.7	63.8	31.7
Runoff (in/ac)	4.5	2.7	15.3	0.5
Subsurface Flow (in/ac)	0.2	0.0	0.3	0.1
Percolation (in/ac)	13.6	5.2	24.4	3.7
Evapotranspiration (in/ac)	26.1	3.2	33.0	19.1
Erosion (t/ac)	0.6	0.5	2.4	0.1
P Losses in Erosion (lb/ac)	0.4	0.3	1.1	0.0
P Losses in Runoff (lb/ac)	0.0	0.0	0.0	0.0
P Losses in Percolation (lb/ac)	0.0	0.0	0.1	0.0
N Losses in Erosion (lb/ac)	2.8	2.3	9.8	0.3
N Losses in Runoff (lb/ac)	4.1	5.0	30.3	0.0
N Losses in Lateral Flow (lb/ac)	0.1	0.3	0.9	0.0
N Losses in Percolation (lb/ac)	18.2	13.4	65.1	0.0
Denitrification (lb/ac)	1.0	0.5	2.1	0.0
Ammonia Volatilization (lb/ac)	0.0	0.0	0.0	0.0
Nitrogen Fixation (lb/ac)	134.9	91.4	0.0	0.0
Nitrogen in Corn Yield (lb/ac)	115.1	18.2	138.3	70.5
Nitrogen in Wheat Yield (lb/ac)	91.9	10.0	108.0	76.7
Nitrogen in Soybean Yield (lb/ac)	132.4	25.9	186.5	87.5
Fertilizer Nitrogen (lb/ac)	85			

Table 8.3
Cash Grain Operation in the Coastal Plain
Average Annual Hydrology and Erosion For Rotation Years
Inorganic Fertilizer

Rotation Year	Runoff (in/ac)	Lateral Flow (in/ac)	Percolation (in/ac)	Erosion (t/ac)
Year 1	4.6	0.2	14.8	1.0
Year 2	2.9	0.2	10.0	0.2
Year 3	6.8	0.2	17.1	0.9
Year 4	3.8	0.2	13.1	0.3

Table 8.4
Cash Grain Operation in the Coastal Plain
Average Annual Nitrogen Losses For Rotation Years
Inorganic Fertilizer

	Nitrogen Losses (lb/ac)				
Rotation Year	**Erosion**	**Runoff**	**Lateral Flow**	**Percolation**	**Total**
Year 1	4.7	4.9	0.2	23.6	33.4
Year 2	0.7	3.9	0.0	13.4	18.0
Year 3	4.2	6.2	0.2	20.5	31.1
Year 4	1.3	1.4	0.0	15.4	18.2
Average	2.8	4.1	0.1	18.2	25.2

Table 8.5
Cash Grain Operation in the Coastal Plain
Average Annual Phosphorus Losses For Rotation Years
Inorganic Fertilizer

	Phosphorus Losses (lb/ac)			
Rotation Year	**Erosion**	**Runoff**	**Percolation**	**Total**
Year 1	0.5	0.0	0.0	0.6
Year 2	0.1	0.0	0.0	0.1
Year 3	0.5	0.0	0.0	0.6
Year 4	0.2	0.0	0.0	0.2
Average	0.4	0.0	0.0	0.4

Table 8.1
Cash Grain Operation in the Coastal Plain
Caroline County, MD
Sassafras Loamy Sand 0-2% slope
Inorganic Fertilizer

	Year 1	
Apr 20	Plant no-till corn	
Apr 20	Fertilize	20 lb N/ac-20 lb P/ac
Apr 20	Fertilize	50 lb N/ac
Jun 15	Sidedress	50 lb N/ac
Sep 25	Harvest corn grain	
Oct 1	Moldboard plow	
Oct 10	Fertilize	15 lb N/ac-30 lb P/ac
Oct 10	Disc or harrow	
Oct 10	Plant wheat or barley	
	Year 2	
Feb 20	Fertilize	40 lb N/ac
Mar 20	Fertilize	50-60 lb N/ac
Jun 23	Harvest small grain	
Jun 24	Plant no-till soybeans	
Nov 10	Harvest soybeans	
	Year 3	
May 1	Chisel plow	
May 15	Fertilize	10 lb N/ac-20 lb P/ac
May 15	Plant soybeans	

Table 8.1
Cash Grain Operation in the Coastal Plain
Caroline County, MD
Sassafras Loamy Sand 0-2% slope
Inorganic Fertilizer

Oct 15	Harvest soybeans	
Oct 16	Chisel plow	
Oct 20	Fertilize	15 lb N/ac-30 lb P /ac
Oct 20	Plant small grain	
	Year 4	
Feb 20	Fertilize	40 lb N/ac
Mar 20	Fertilize	50-60 lbs N/ac
Jun 25	Harvest small grain	
Jun 26	Plant no-till soybeans	
Nov 10	Harvest soybeans	

Table 9.1
Poultry and Cash Grain Operation in the Coastal Plain
Matapeake Silt Loam 0-2% Slope
Before Nutrient Management

Year 1

Mar 15	Manure Incorporate with chisel plow	5.0 tons\ac 60 lbs N/ton, 60 lbs P/ton
Apr 10	Plant corn	
Apr 10	Starter fertilizer	30 lbs N/ac, 30 lbs P/ac
Oct 12	Harvest corn	160-180 Bu/ac
Oct 29	Plant wheat	

Year 2

Feb 8	Top dress fertilizer	30 lbs N/ac
Mar 17	Top dress fertilizer	40 lbs N/ac
May 30	Harvest wheat	75 Bu/ac
Jun 12	Plant soybeans	
Nov 5	Harvest soybeans	39 Bu/ac
Nov 15	Apply lime	

Year 3

Apr 17	Manure Incorporate with chisel plow	4.0 tons\ac 60 lbs N/ton, 60 lbs P/ton
May 20	Plant sorghum	
Nov 10	Harvest sorghum	

Table 9.2
Poultry and Cash Grain Operation in the Coastal Plain
Average Annual Hydrology and Nutrient Losses
Before Nutrient Management

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	44.3	7.8	63.8	31.7
Runoff (in/ac)	6.1	3.6	15.6	0.6
Lateral Flow (in/ac)	0.1	0.0	0.2	0.1
Percolation (in/ac)	8.8	4.2	19.6	3.0
Evapotranspiration (in/ac)	29.3	3.4	36.3	23.2
Erosion (t/ac)	1.1	0.8	4.0	0.2
P Losses in Erosion (lb/ac)	3.1	2.9	11.4	0.3
P Losses in Runoff (lb/ac)	1.0	1.0	3.6	0.0
P Losses in Percolation (lb/ac)	0.1	0.0	0.2	0.0
N Losses in Erosion (lb/ac)	8.9	7.2	28.6	1.2
N Losses in Runoff (lb/ac)	10.6	6.8	25.9	0.0
N Losses in Lateral Flow (lb/ac)	0.1	0.3	0.9	0.0
N Losses in Percolation (lb/ac)	29.5	21.2	77.6	0.0
Denitrification (lb/ac)	2.1	1.2	4.9	0.0
Ammonia Volatilization (lb/ac)	16.7	12.1	30.4	0.0
Nitrogen Fixation (lb/ac)	61.7	91.9	0.0	0.0
Nitrogen in Corn Yield (lb/ac)	135.0	12.0	150.8	102.6
Nitrogen in Wheat Yield (lb/ac)	75.2	14.1	111.5	59.8
Nitrogen in Soybean Yield (lb/ac)	154.4	19.1	182.0	117.8
Nitrogen in Sorghum Yield (lb/ac)	93.7	4.4	100.8	83.9
Fertilizer Nitrogen (lb/ac)	213.3			

Table 9.3
Poultry and Cash Grain Operation in the Coastal Plain Average Annual Hydrology and Erosion For Rotation Years Before Nutrient Management

Rotation Year	Runoff (in/ac)	Lateral Flow (in/ac)	Percolation (in/ac)	Erosion (t/ac)
Year 1	6.2	0.1	9.8	1.6
Year 2	3.9	0.1	7.0	1.0
Year 3	8.3	0.1	9.7	0.7

Table 9.4
Poultry and Cash Grain Operation in the Coastal Plain Average Annual Nitrogen Losses For Rotation Years Before Nutrient Management

			Nitrogen Losses (lb/ac)		
Rotation Year	**Erosion**	**Runoff**	**Lateral Flow**	**Percolation**	**Total**
Year 1	14.7	12.5	0.1	41.0	68.3
Year 2	6.6	5.0	0.0	17.2	28.8
Year 3	5.4	14.5	0.2	30.4	50.4
Average	8.9	10.6	0.1	29.5	49.2

Table 9.5
Poultry and Cash Grain Operation in the Coastal Plain Average Annual Phosphorus Losses For Rotation Years Before Nutrient Management

	Phosphorus Losses (lb/ac)			
Rotation Year	**Erosion**	**Runoff**	**Percolation**	**Total**
Year 1	5.9	1.3	0.1	7.3
Year 2	1.7	0.2	0.1	2.0
Year 3	1.8	1.3	0.1	3.2
Average	3.1	1.0	0.1	4.2

Table 9.6
Poultry and Cash Grain Operation in the Coastal Plain
Average Annual Hydrology and Nutrient Losses
Nutrient Management

	Mean	Standard Deviation	Maximum	Minimum
Precipitation (in/ac)	44.3	7.8	63.8	31.7
Runoff (in/ac)	6.1	3.6	15.6	0.6
Lateral Flow (in/ac)	0.1	0.0	0.2	0.1
Percolation (in/ac)	8.8	4.2	19.6	3.0
Evapotranspiration (in/ac)	29.3	3.4	36.3	23.2
Erosion (t/ac)	1.1	0.8	4.0	0.2
P Losses in Erosion (lb/ac)	2.4	2.1	8.6	0.2
P Losses in Runoff (lb/ac)	0.4	0.6	1.8	0.0
P Losses in Percolation (lb/ac)	0.1	0.0	0.2	0.0
N Losses in Erosion (lb/ac)	7.4	5.9	22.9	1.1
N Losses in Runoff (lb/ac)	9.0	6.1	25.9	0.0
N Losses in Lateral Flow (lb/ac)	0.0	0.2	0.9	0.0
N Losses in Percolation (lb/ac)	12.6	12.5	50.9	0.0
Denitrification (lb/ac)	1.2	0.8	3.3	0.0
Ammonia Volatilization (lb/ac)	11.2	8.3	21.3	0.0
Nitrogen Fixation (lb/ac)	73.9	109.4	0.0	0.0
Nitrogen in Corn Yield (lb/ac)	132.1	10.8	144.6	102.6
Nitrogen in Wheat Yield (lb/ac)	73.4	11.8	100.8	59.8
Nitrogen in Soybean Yield (lb/ac)	153.9	19.0	182.0	117.8
Nitrogen in Sorghum Yield (lb/ac)	93.7	4.4	100.8	83.9
Fertilizer Nitrogen (lb/ac)	153.3			

Table 9.7
Poultry and Cash Grain Operation in the Coastal Plain Average Annual Nitrogen Losses For Rotation Years After Nutrient Management

Rotation Year	Nitrogen Losses (lb/ac) Erosion	Runoff	Lateral Flow	Percolation	Total
Year 1	12.0	10.1	0.0	19.2	41.3
Year 2	5.7	4.3	0.0	2.9	12.9
Year 3	4.4	12.6	0.1	15.6	32.7
Average	7.4	9.0	0.0	12.6	29.0

Table 9.8
Poultry and Cash Grain Operation in the Coastal Plain Average Annual Phosphorus Losses For Rotation Years After Nutrient Management

	Phosphorus Losses (lb/ac)			
Rotation Year	**Erosion**	**Runoff**	**Percolation**	**Total**
Year 1	4.5	0.6	0.1	5.2
Year 2	1.3	0.1	0.1	1.5
Year 3	1.3	0.7	0.1	2.1
Average	2.4	0.4	0.1	2.9

Table 9.9
Poultry and Cash Grain Operation in the Coastal Plain Sensitivity of Nitrogen Losses and Reduction Efficiency to the Percent of the Organic Nitrogen Available in First Year Represented As Nitrate

% Available 1st Year Nitrogen	Nitrogen Losses Before Nutrient Management (lb/ac)					Nitrogen Losses After Nutrient Management (lb/ac)					
	Erosion	Runoff	Lateral Flow	Percolation	Total	Erosion	Runoff	Lateral Flow	Percolation	Total	Reduction Efficiency
0%	10.4	8.7	0.1	22.8	41.9	8.3	7.6	0.0	9.8	25.7	39%
50%	8.9	10.6	0.1	29.5	49.2	7.4	9.0	0.0	12.6	29.0	41%
75%	8.1	11.9	0.3	35.7	56.0	7.0	9.6	0.0	14.1	30.7	45%
100%	7.5	12.8	0.4	41.9	62.6	6.5	10.4	0.0	16.2	33.2	47%

Table 9.10
Poultry and Cash Grain Operation in the Coastal Region
Effect of Slope on Simulated Hydrology

Slope	Runoff (in/ac)	Lateral Flow (in/ac)	Percolation (in/ac)	Erosion (t/ac)
%1	6.1	0.1	8.8	1.1
%5	7.3	0.6	6.9	3.7
%8	7.9	0.9	5.9	6.6

Table 9.11
Poultry and Cash Grain Operation in the Coastal Plain
Effect of Slope on Simulated Nitrogen Losses and Reduction Efficiency

	Nitrogen Losses Before Nutrient Management (lb/ac)					Nitrogen Losses After Nutrient Management (lb/ac)					
Slope	Erosion	Runoff	Lateral Flow	Percolation	Total	Erosion	Runoff	Lateral Flow	Percolation	Total	Reduction Efficiency
%1	8.9	10.6	0.1	29.5	49.2	7.4	9.0	0.0	12.6	29.0	41%
%5	22.4	14.6	2.3	19.6	59.0	18.6	12.1	1.2	8.0	40.0	32%
%8	36.2	16.8	3.4	13.7	70.0	30.2	13.9	2.1	5.8	52.0	26%

Table 9.12
Poultry and Cash Grain Operation in the Coastal Plain
Effect of Slope on Simulated Phosphorus Losses and Reduction Efficiency

	Phosphorus Losses Before Nutrient Management (lb/ac)				Phosphorus Losses After Nutrient Management (lb/ac)				
Slope	Erosion	Runoff	Percolation	Total	Erosion	Runoff	Percolation	Total	Reduction Efficiency
%1	3.1	1.0	0.1	4.2	2.4	0.4	0.1	2.9	31%
%5	8.0	1.2	0.1	9.2	6.1	0.5	0.1	6.7	27%
%8	12.9	1.2	0.0	14.2	9.9	0.6	0.0	10.5	26%

Table 10.1
Nutrient Reduction Efficiencies and Excess Nitrogen Losses

Scenario	State	Nitrogen Reduction Efficiency	Excess Nitrogen Losses	Phosphorus Reduction Efficiency
Poultry and Dairy Operation in Limestone Valley Region (Poultry Litter)	VA	24%	13%	36%
Poultry and Dairy Operation in Limestone Valley Region (Dairy Manure)	VA	24%	9%	36%
Dairy and Swine Operation in Ridge and Valley Region (Dairy Manure)	PA	43%	67%	29%
Dairy and Swine Operation in Ridge and Valley Region (Hog Manure)	PA	62%	65%	43%
Dairy Operation in Piedmont Region (Silage Corn)	PA	75%	78%	42%
Dairy Operation in Piedmont Region (Grain Corn)	PA	54%	64%	52%
Poultry Operation in Coastal Plain	MD	33%	56%	0%
Poultry and Cash Grain Operation in Coastal Plain	MD	41%	58%	31%

Table 10.2
Annual Nutrient Applications and Nutrient Losses After Nutrient Management (lb/ac)

Scenario	State	Nitrogen			Phosphorus		
		Inputs[1]	Losses	Percent	Inputs	Losses	Percent
Poultry and Dairy Operation in Limestone Valley Region	VA	343.7	46.2	13%	117	10.7	9%
Dairy and Swine Operation in Ridge and Valley Region (Dairy Manure)	PA	182.4	78.4	43%	36.6	2.5	7%
Dairy and Swine Operation in Ridge and Valley Region (Hog Manure)	PA	188.8	88.3	47%	90.8	5.3	6%
Dairy Operation in Piedmont Region (Silage Corn)	PA	128.4	44.3	35%	30.4	6.3	21%
Dairy Operation in Piedmont Region (Grain Corn)	PA	141.3	65.5	46%	26.5	2.6	10%
Poultry Operation in Coastal Plain	MD	142.3	29.5	21%	52.1	2.2	4%
Poultry and Cash Grain Operation in Coastal Plain	MD	142.1	29.0	20%	56.7	2.9	5%

[1] Average annual fertilizer application minus average annual volatilization losses.

Table 10.3
Sensitivity of Nitrogen Reduction Efficiencies to Denitrification Losses

		Nitrogen Reduction Efficiency			
Scenario	State	Minimal Denitrification	10% Subsurface Losses	20% Subsurface Losses	50% Subsurface Losses
Dairy and Swine Operation in Ridge and Valley Region (Dairy Manure)	PA	43%	42%	42%	39%
Dairy and Swine Operation in Ridge and Valley Region (Hog Manure)	PA	62%	62%	61%	59%
Dairy Operation in Piedmont Region (Silage Corn)	PA	75%	74%	73%	69%
Dairy Operation in Piedmont Region (Grain Corn)	PA	54%	53%	51%	46%
Poultry Operation in Coastal Plain	MD	33%	33%	32%	32%
Poultry and Cash Grain Operation in Coastal Plain	MD	41%	40%	39%	34%

Table 10.4
Sensitivity of Nitrogen Reduction Efficiencies and Total Nitrogen Losses After Nutrient Management to Slope and Soil Type

			Slope		Soil Type	
Scenario	**State**	**Slope**	**Losses (lb/ac)**	**Efficiency**	**Losses (lb/ac)**	**Efficiency**
Poultry and Dairy Operation in Limestone Valley Region (Poultry Litter)	VA	4.5-20%	22.6-93.1	24-26%	21.4-46.2	24-30%
Dairy and Swine Operation in Ridge and Valley Region (Dairy Manure)	PA	2-10%	73.0-92.4	40-44%	78.4-86.4	42-43%
Dairy and Swine Operation in Ridge and Valley Region (Hog Manure)	PA	2-10%	83.5-100.9	59-63%	85.8-99.9	60-62%
Dairy Operation in Piedmont Region (Silage Corn)	PA	2-10%	28.5-74.2	66-82%	44.0-44.8	75-76%
Dairy Operation in Piedmont Region (Grain Corn)	PA	2-10%	53.8-88.2	47-59%	65.5-70.0	51-54%
Poultry Operation in Coastal Plain	MD	1-8%	29.5-47.6	20-33%	--	--
Poultry and Cash Grain Operation in Coastal Plain	MD	1-8%	29.0-52.0	26-41%	--	--

THE USE OF EPIC TO EVALUATE NUTRIENT LOADS FROM CROP LAND IN THE CHESAPEAKE BAY BASIN

Appendix B: Figures

Ross Mandel
Interstate Commission on the Potomac River Basin
ICPRB Report #97-8
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This publication has been prepared by the staff of the Interstate Commission on the Potomac River Basin. Funds for this project were provided by the United States Government, the U. S. Environmental Protection Agency, and the signatory bodies to the Interstate Commission on the Potomac River Basin: The District of Columbia, Maryland, Pennsylvania, Virginia, and West Virginia. The opinions expressed are those of the authors and should not be construed as representing the opinions or policy of the United States government or any of its agencies, the several states, or the Commissioners of the Interstate Commission on the Potomac River Basin.

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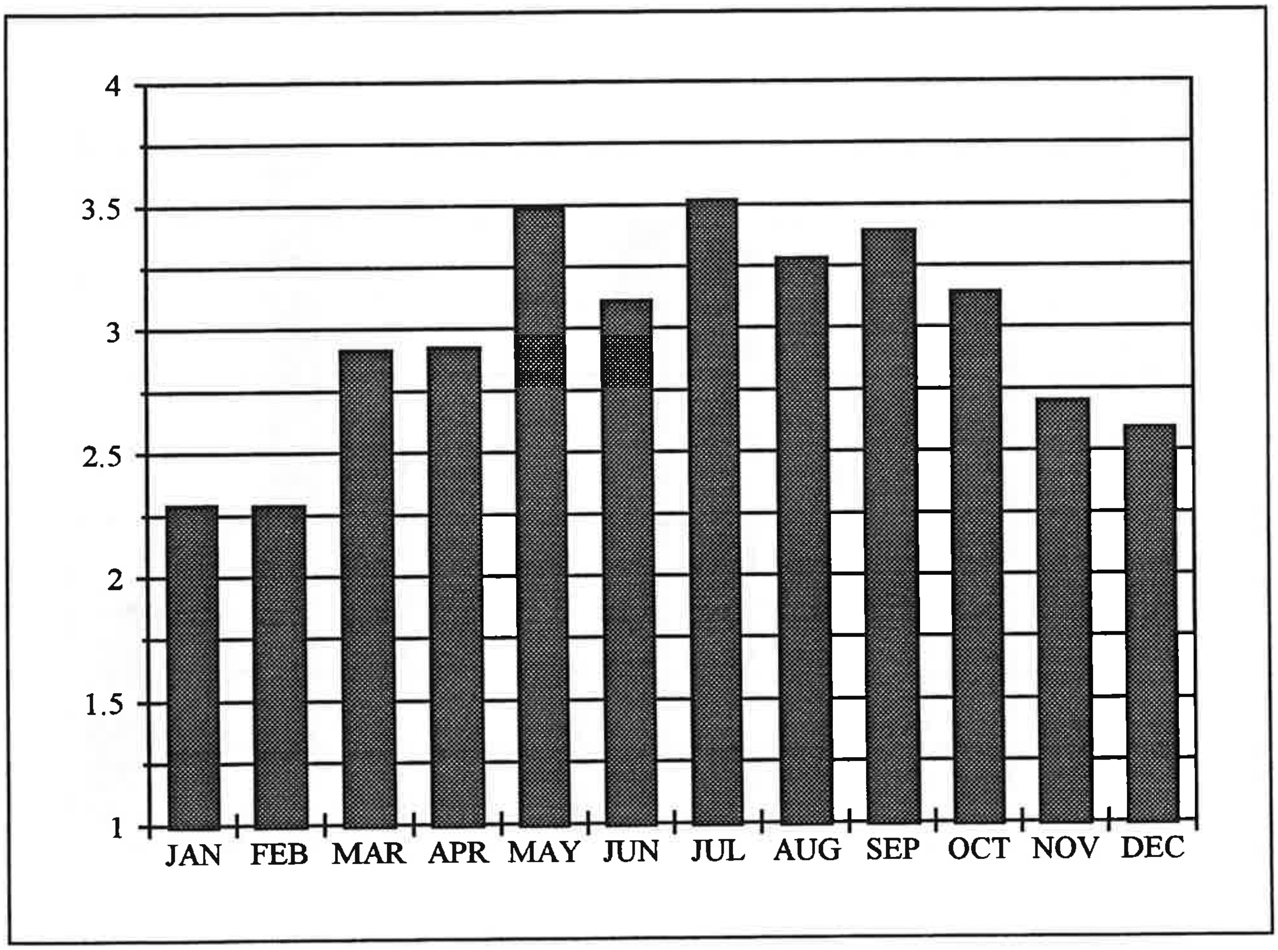

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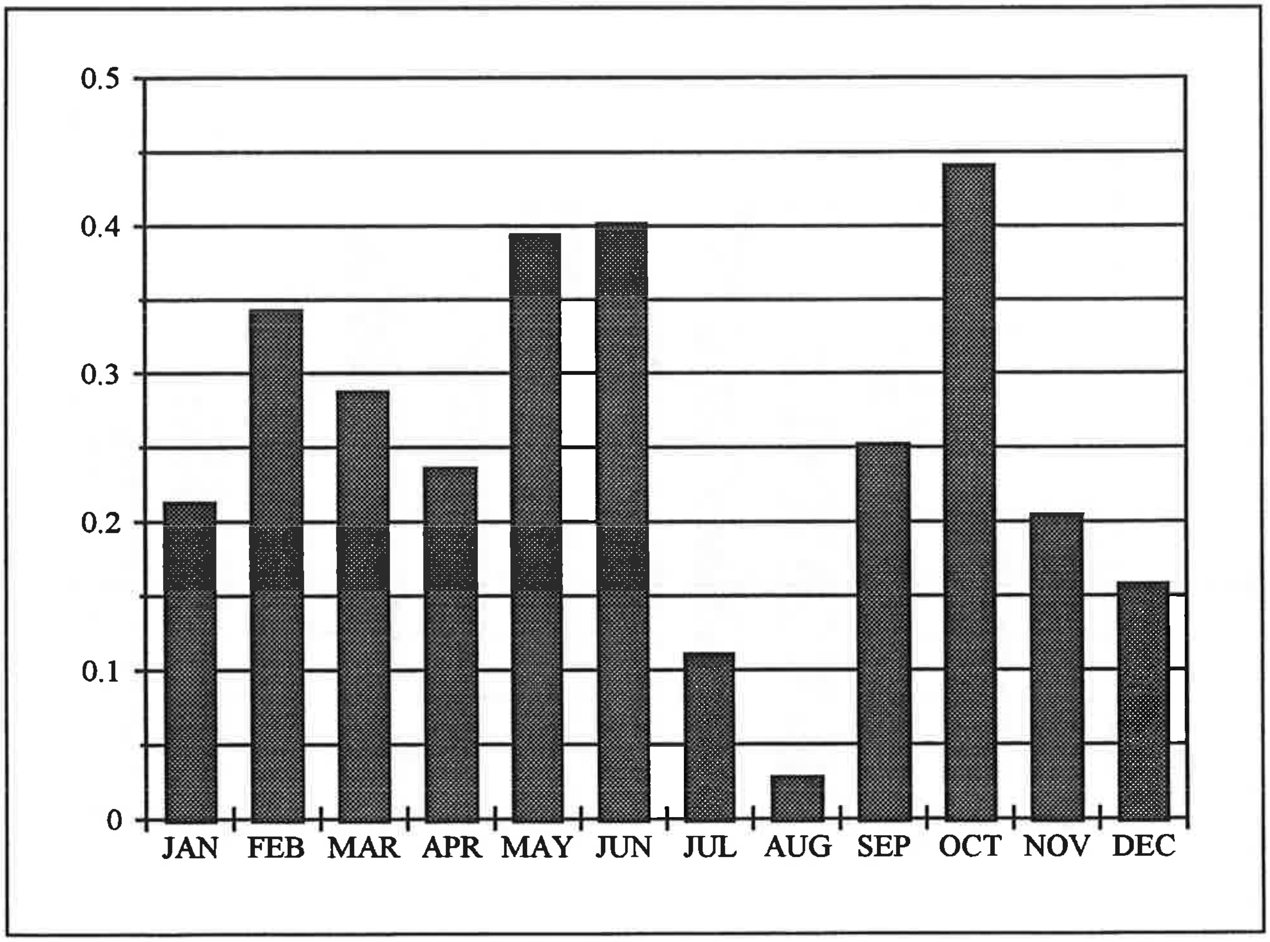

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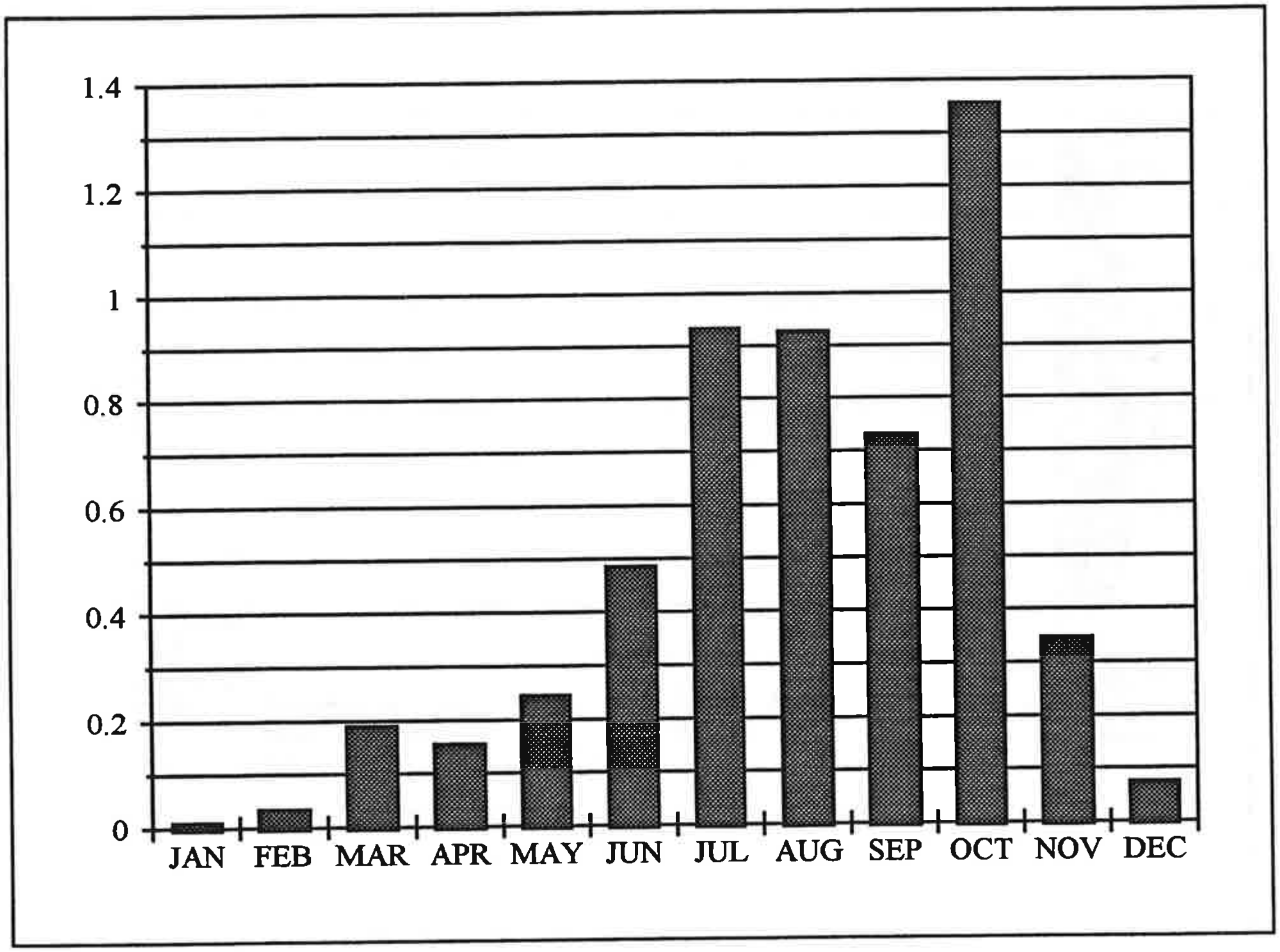

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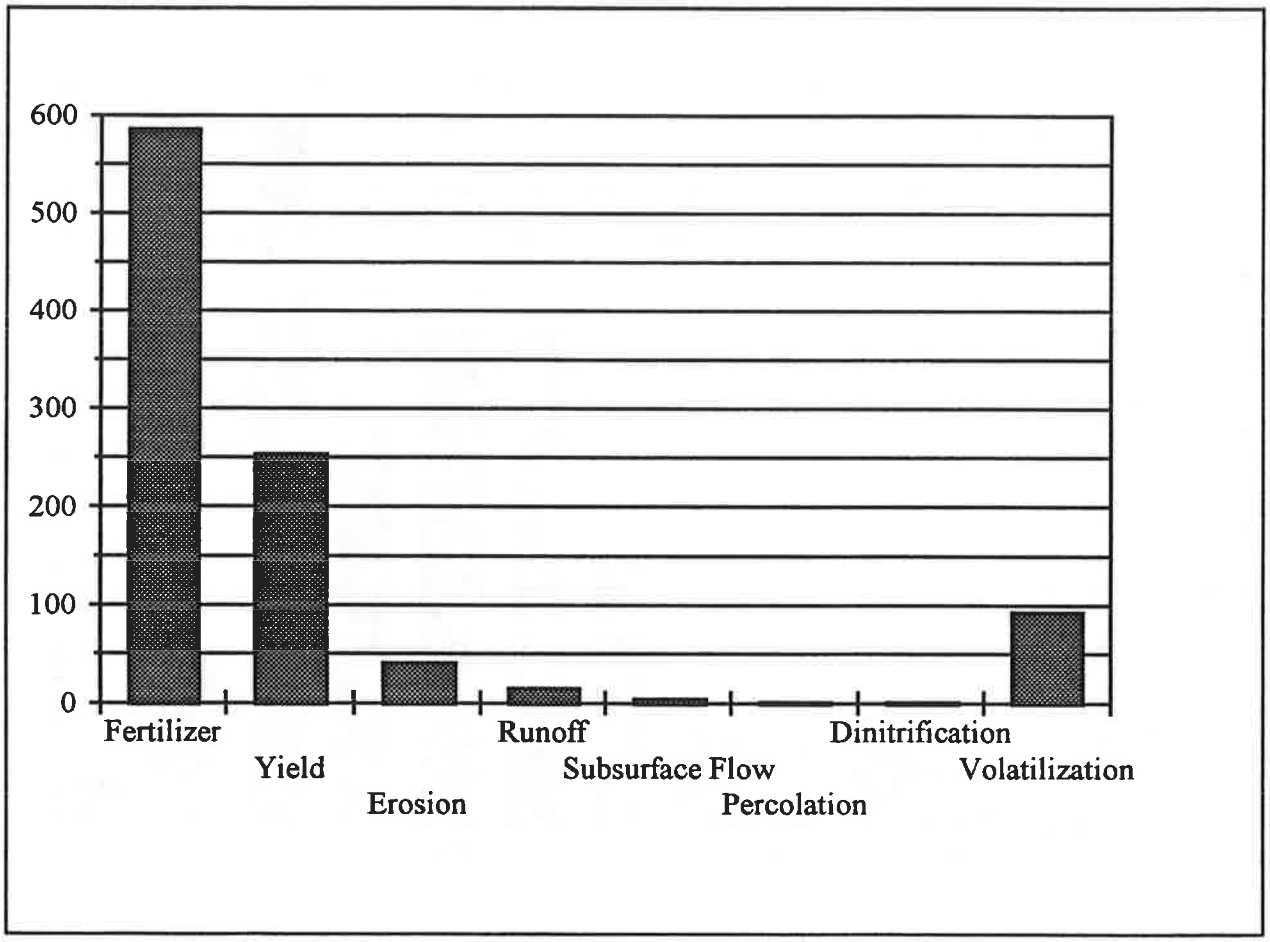

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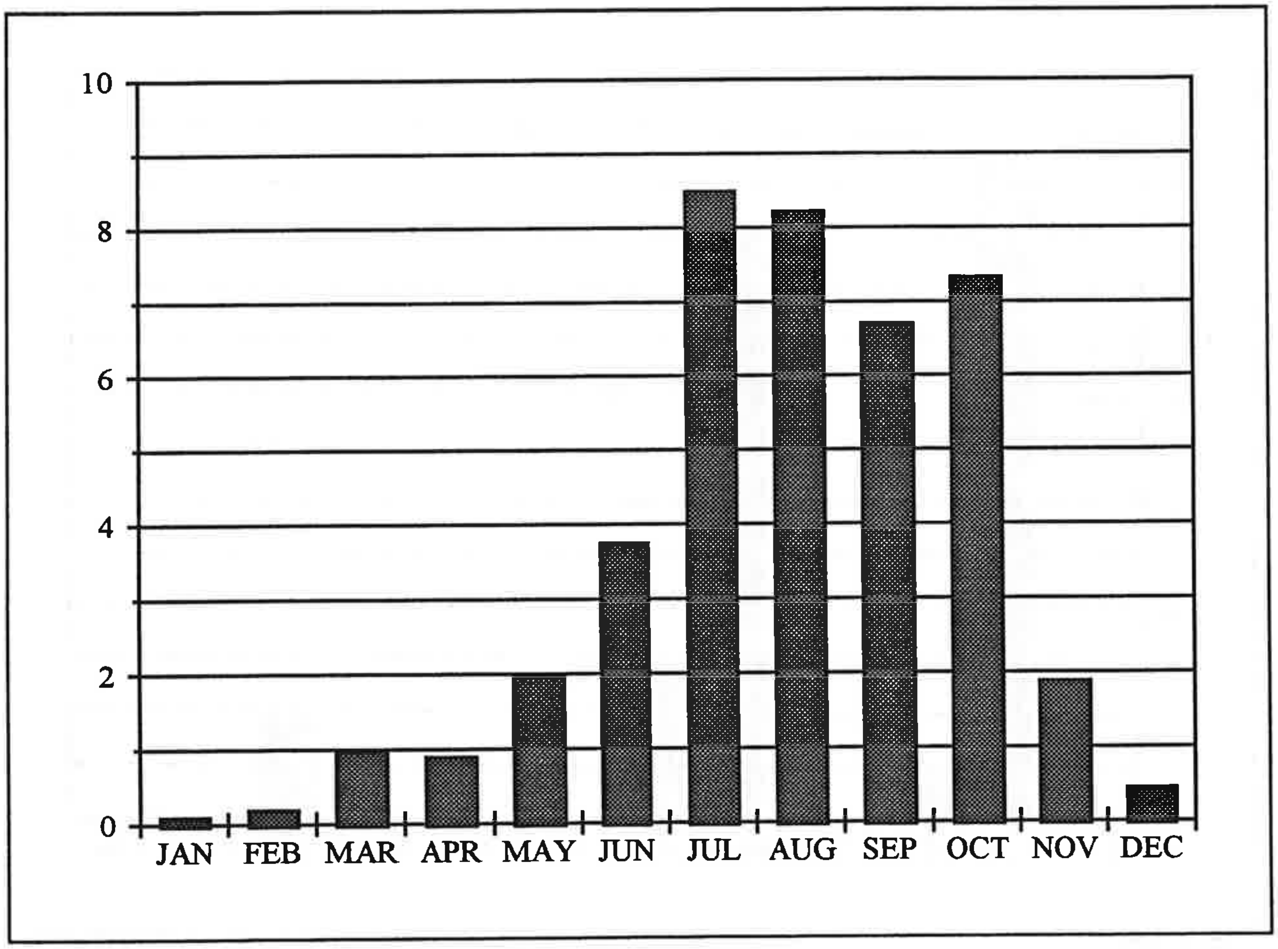

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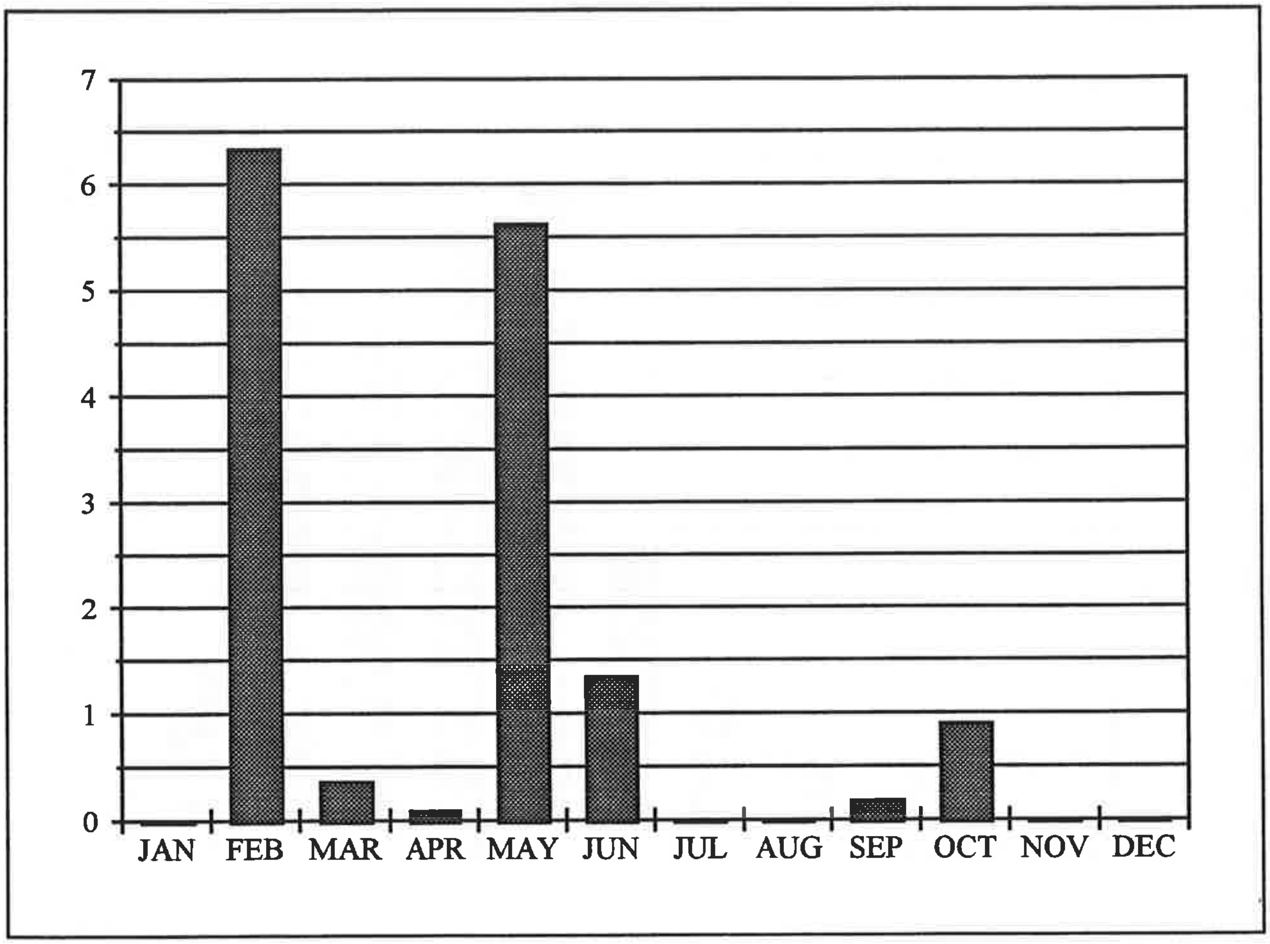

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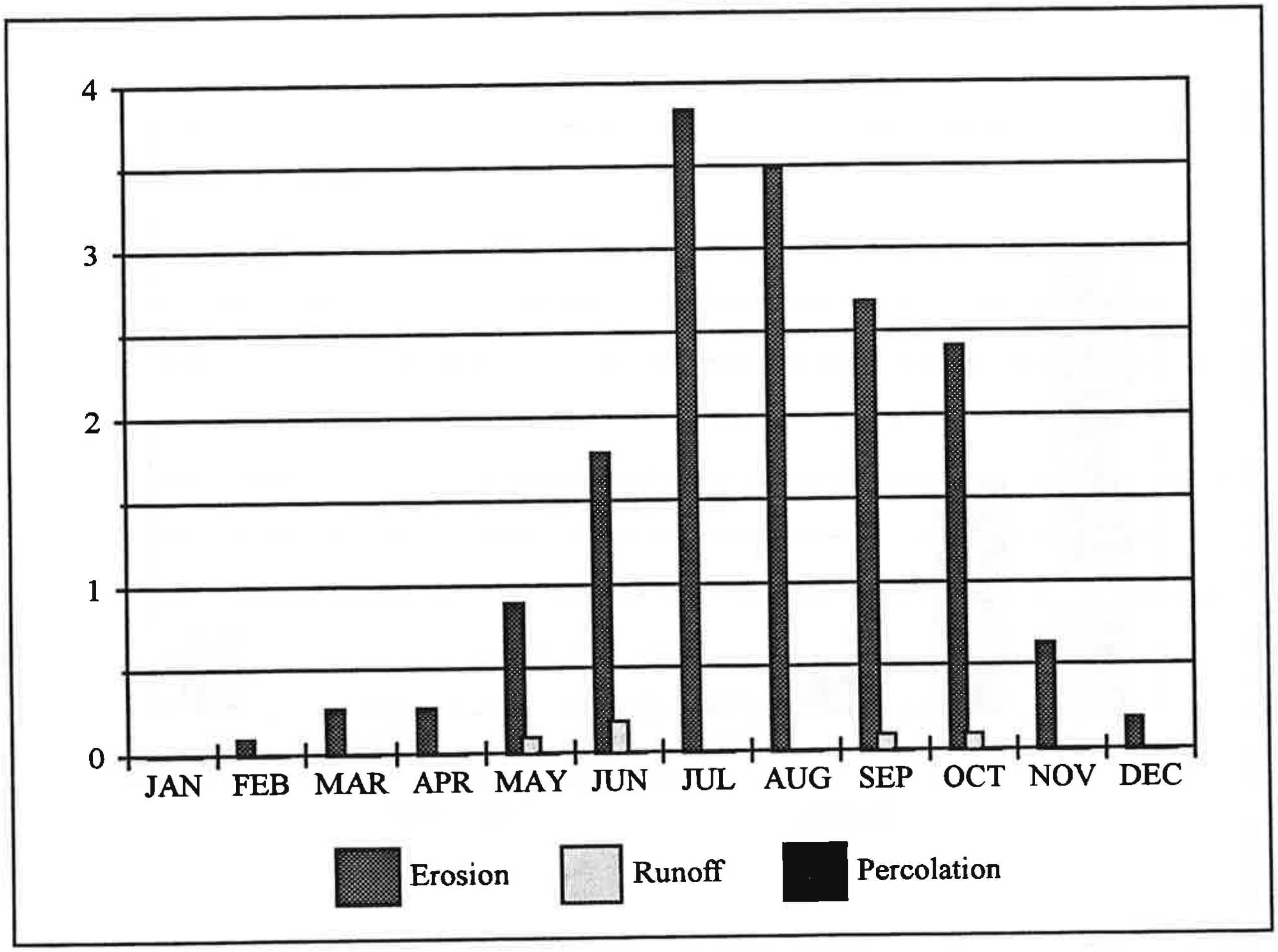

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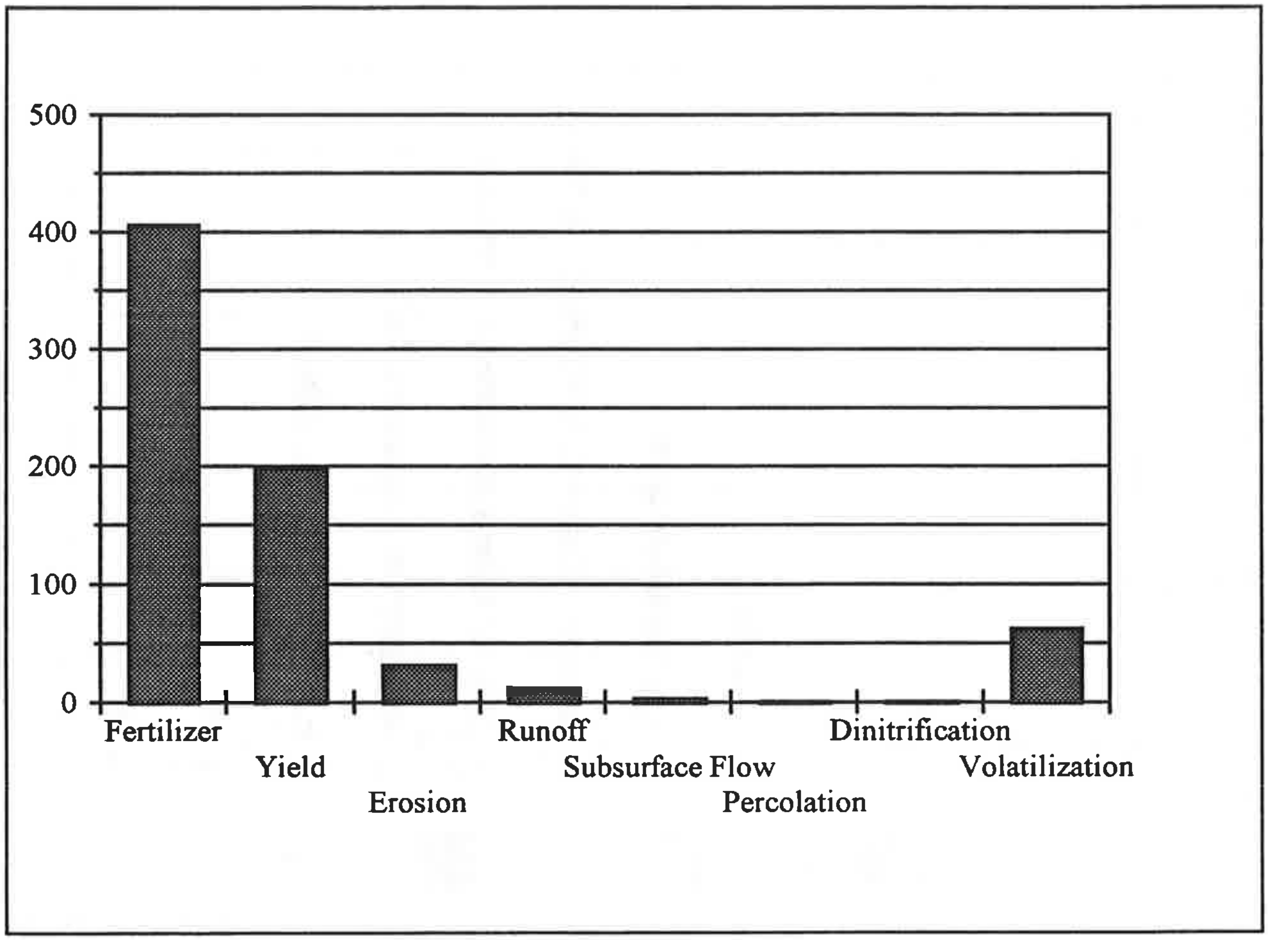

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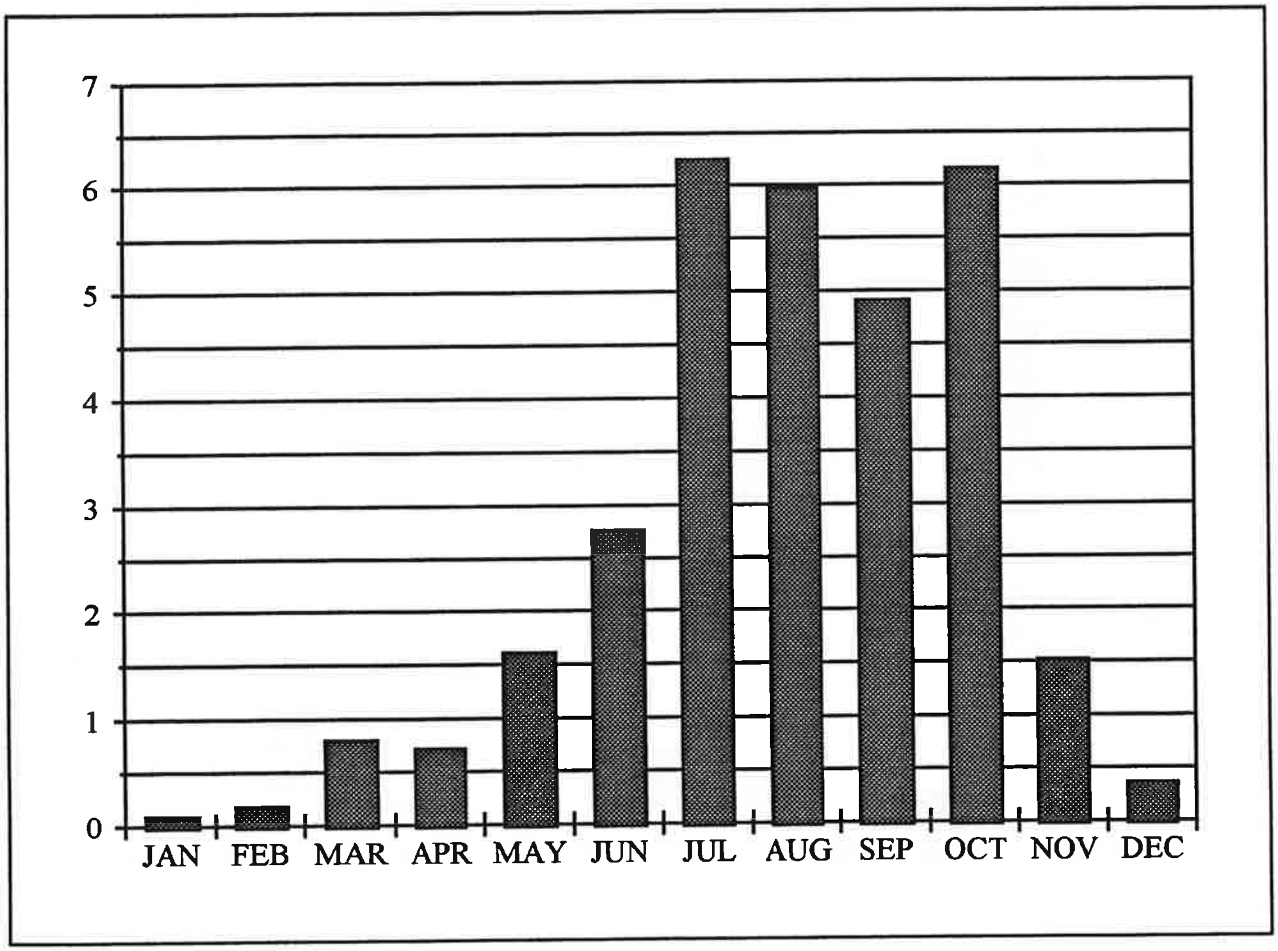

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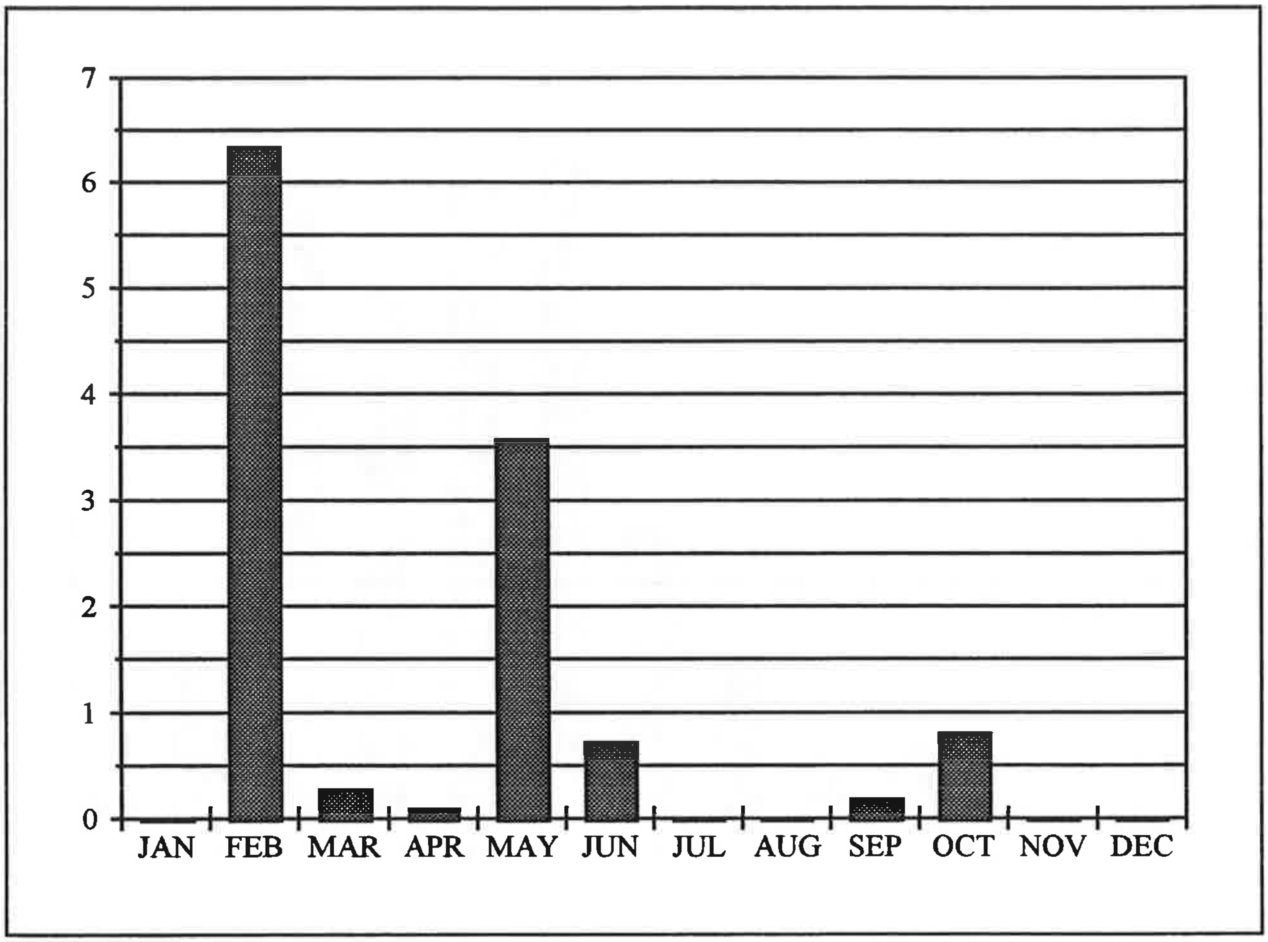

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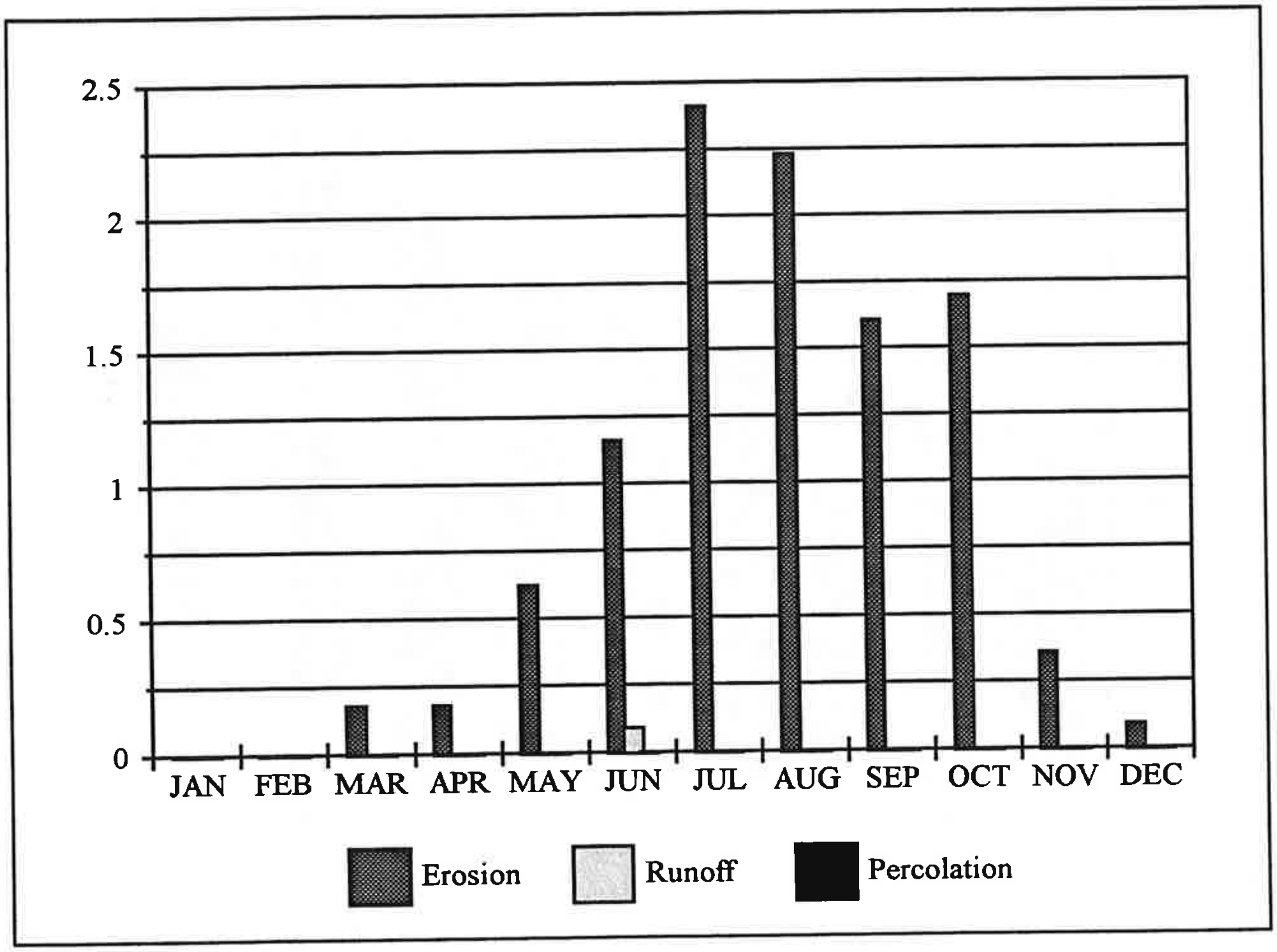

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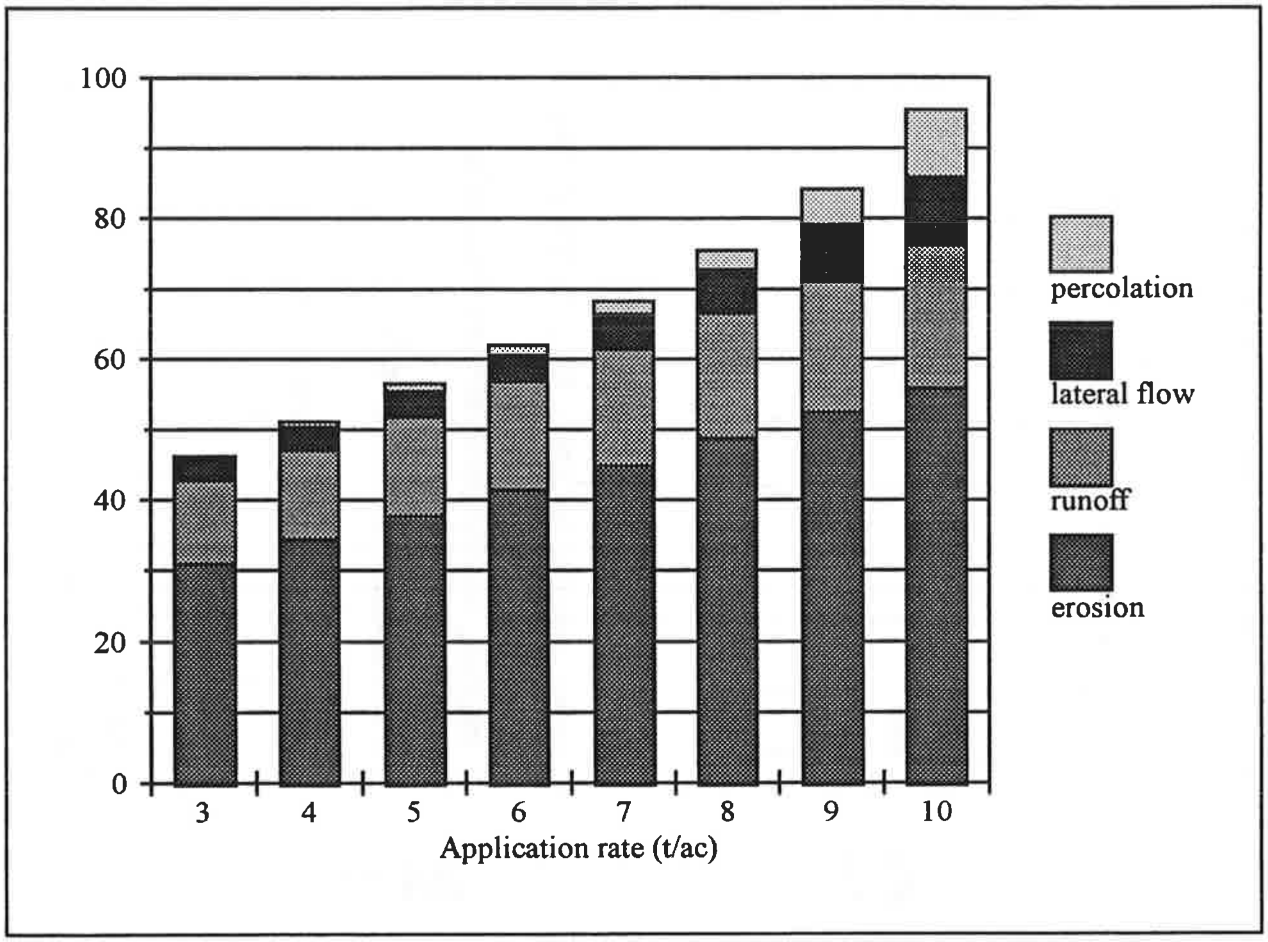

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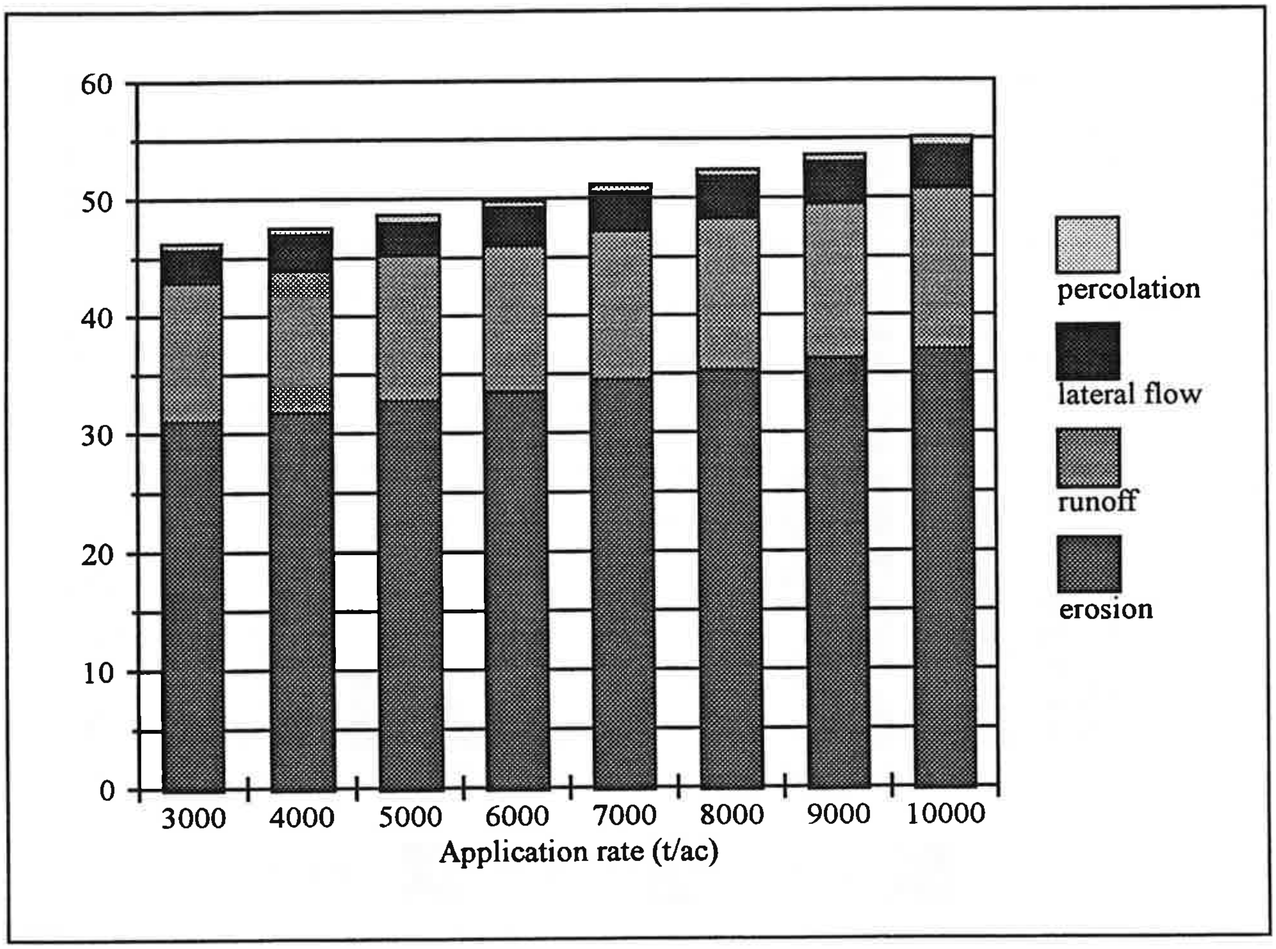

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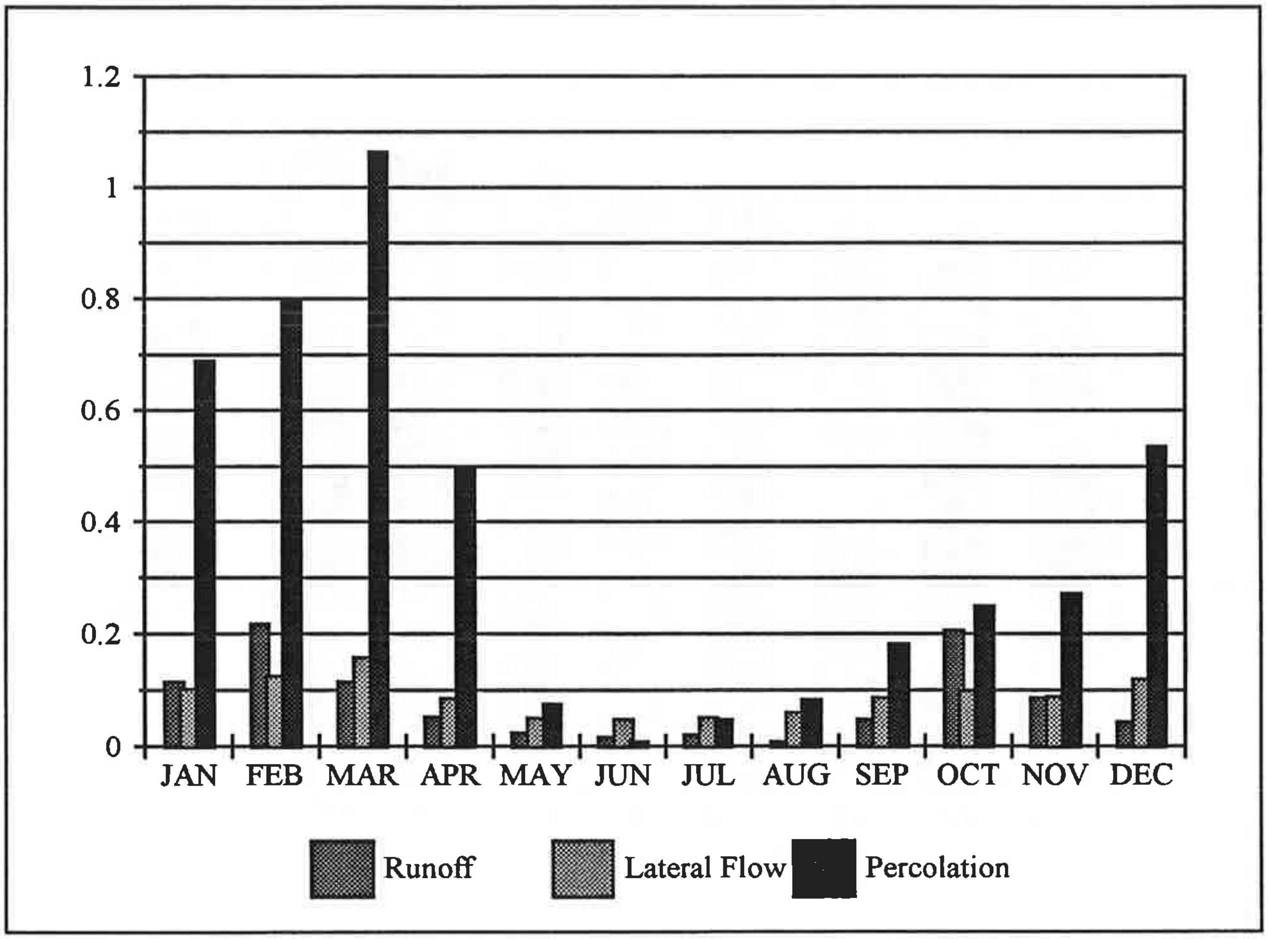

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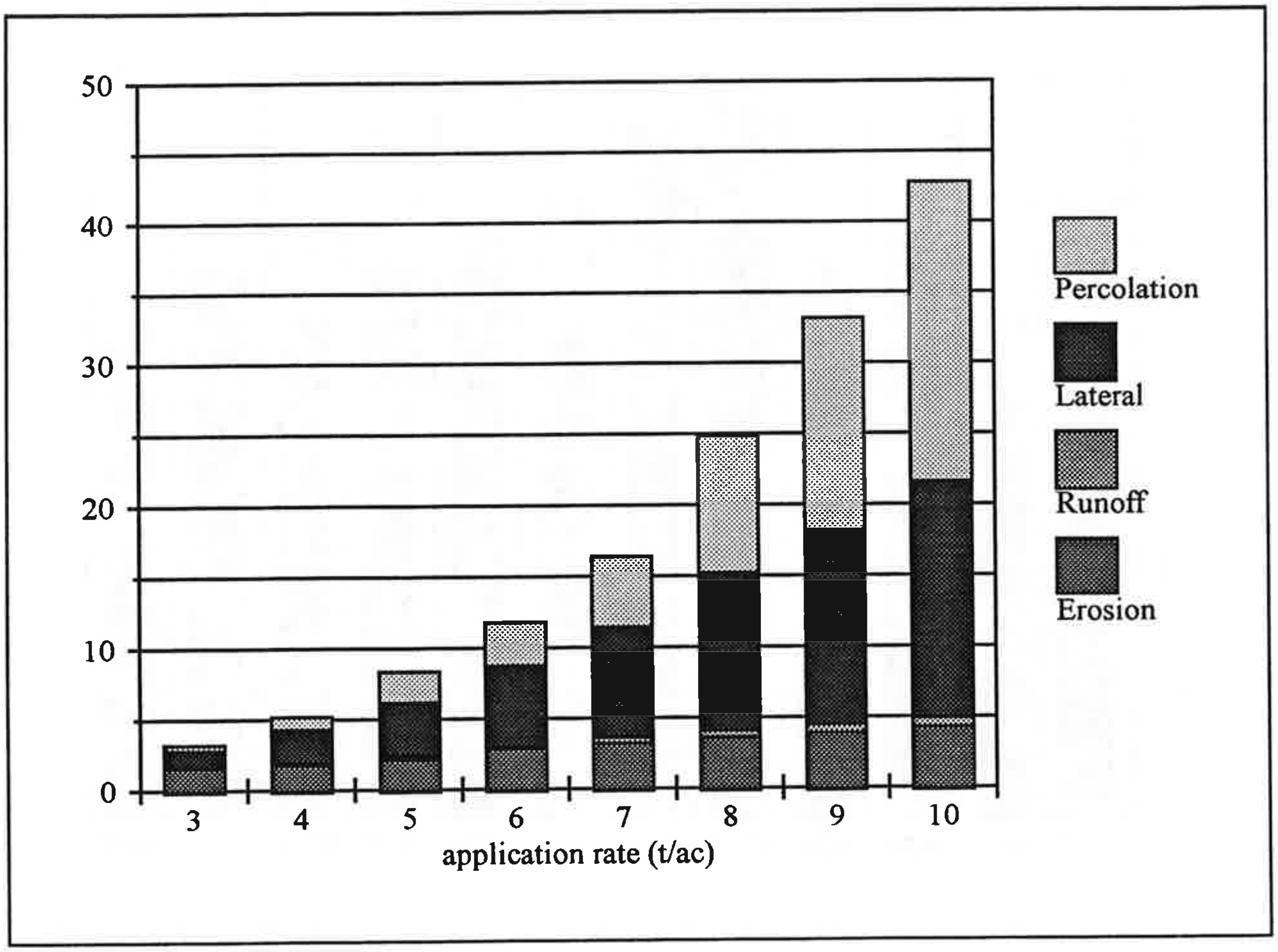

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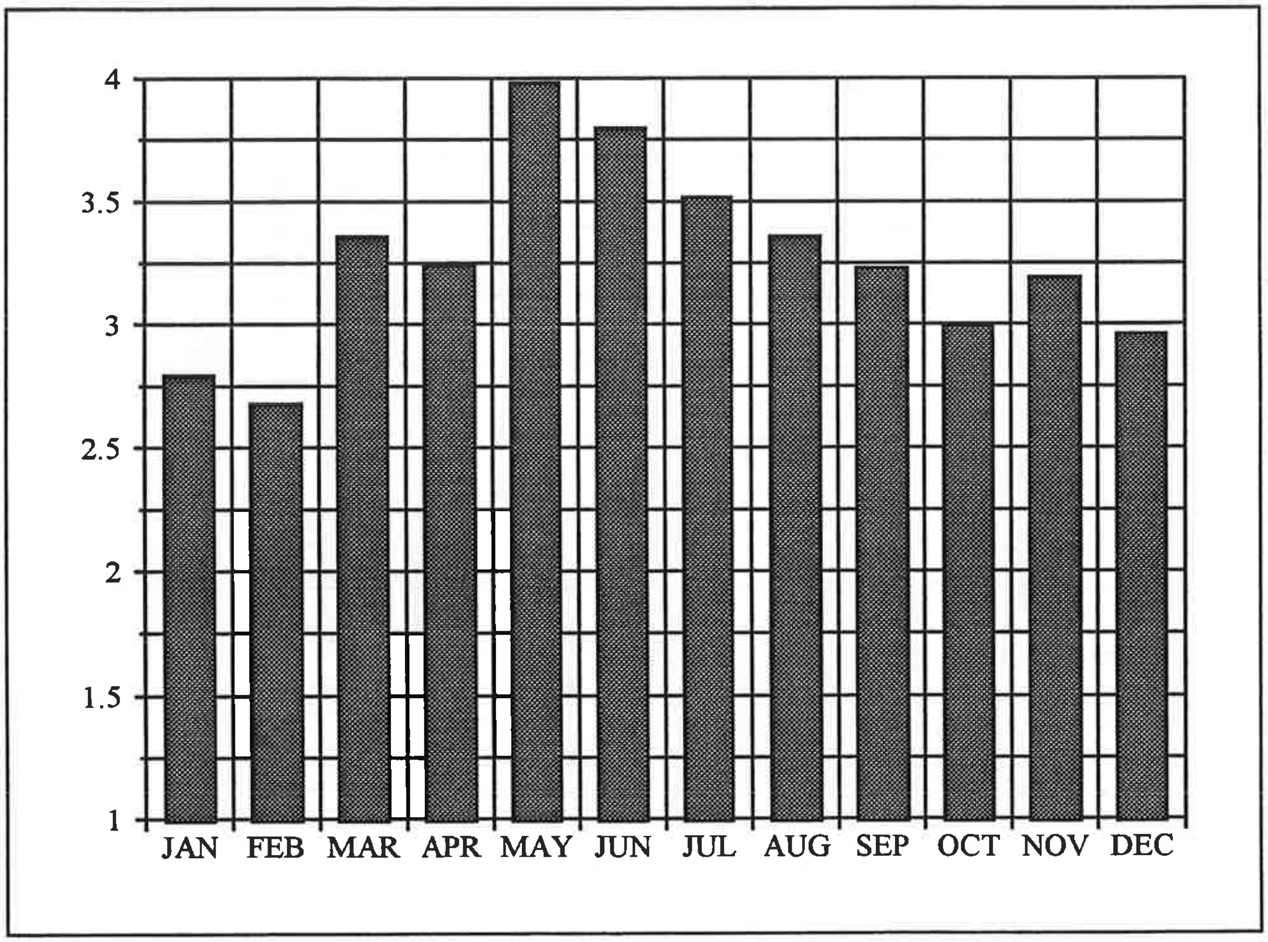

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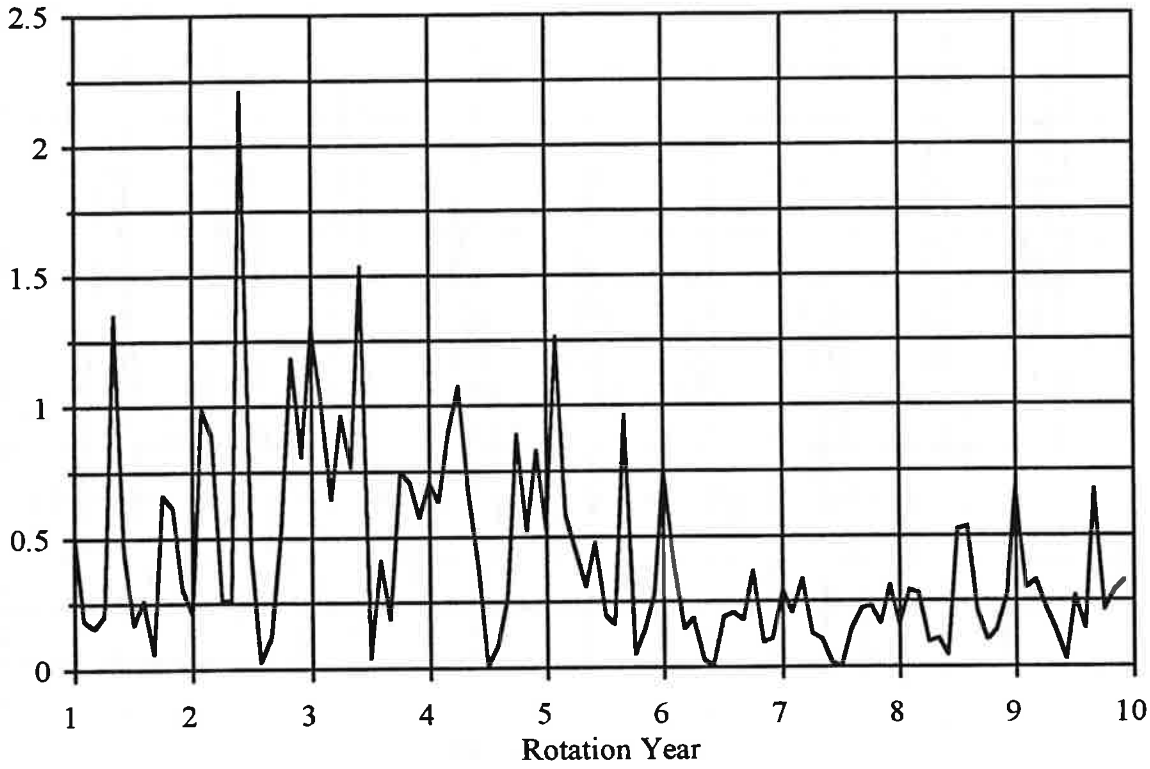

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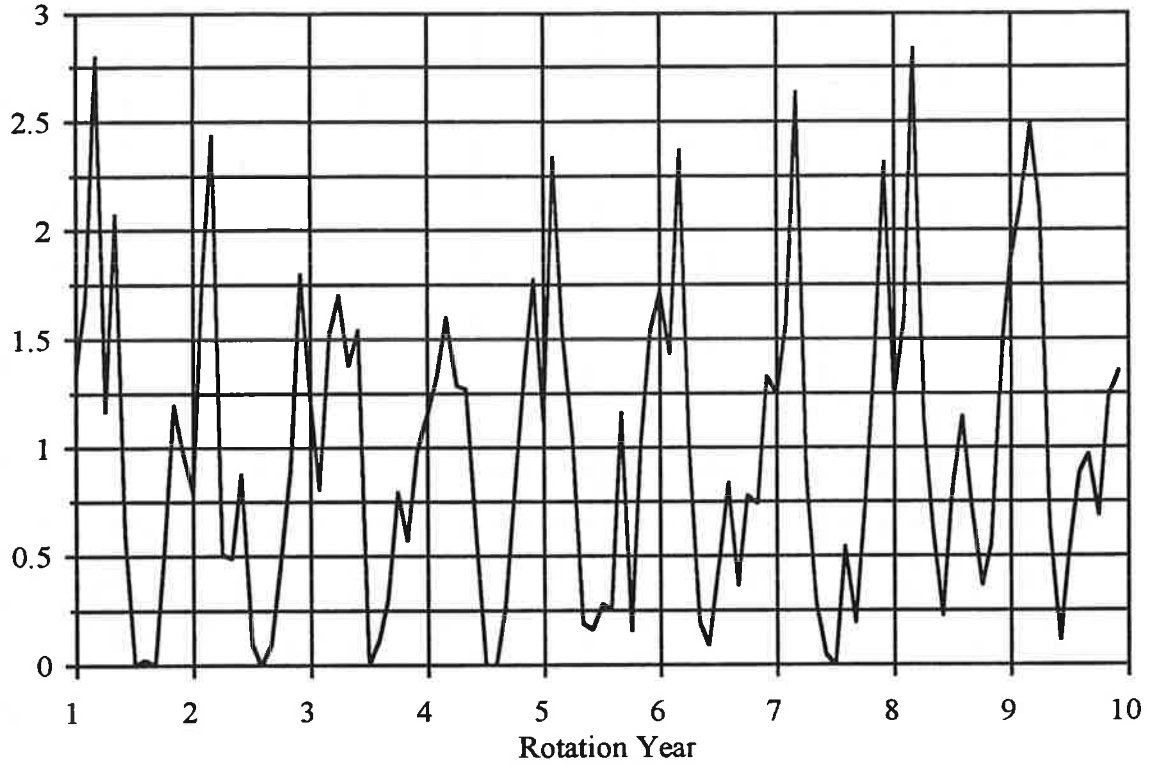

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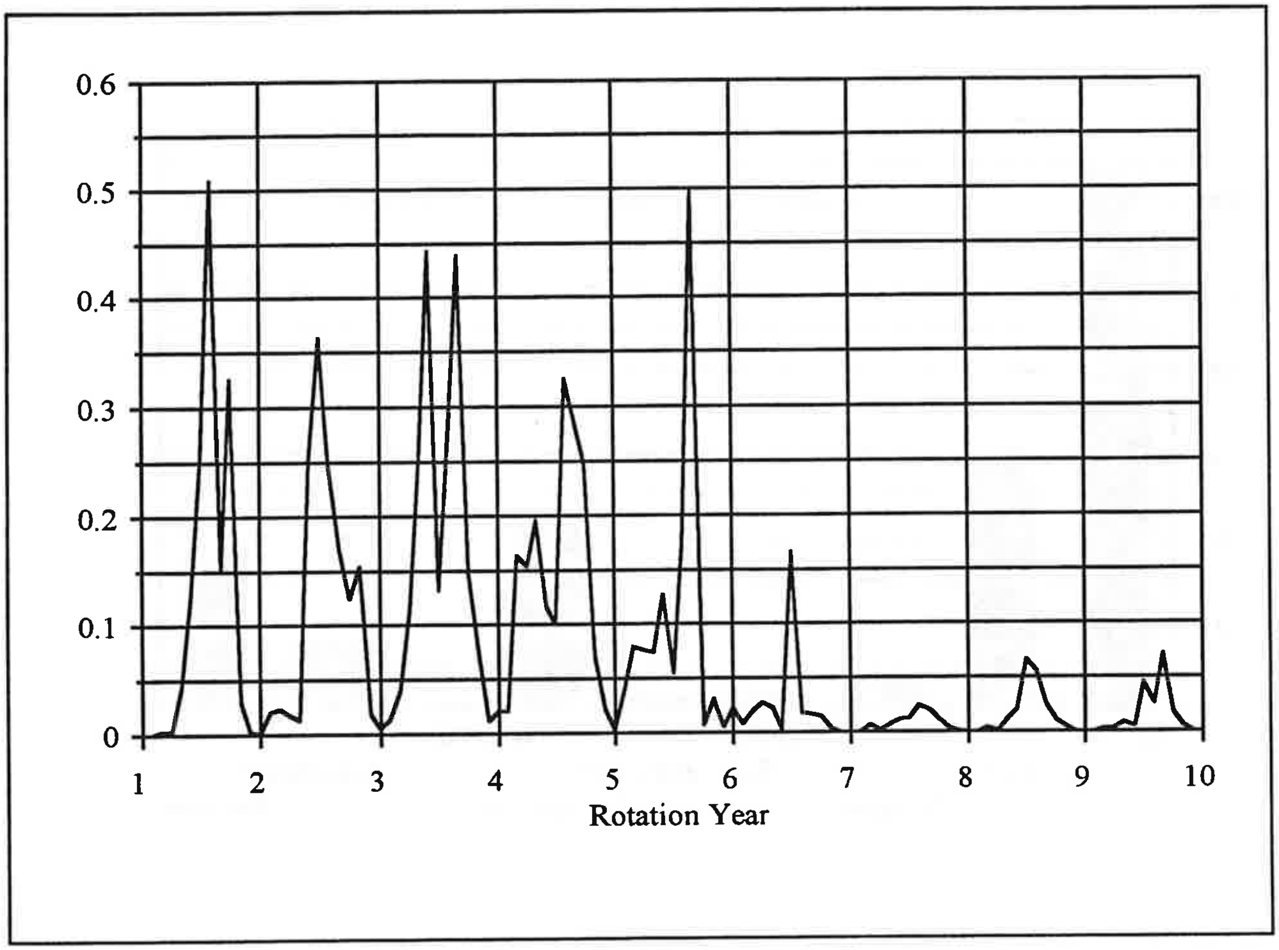

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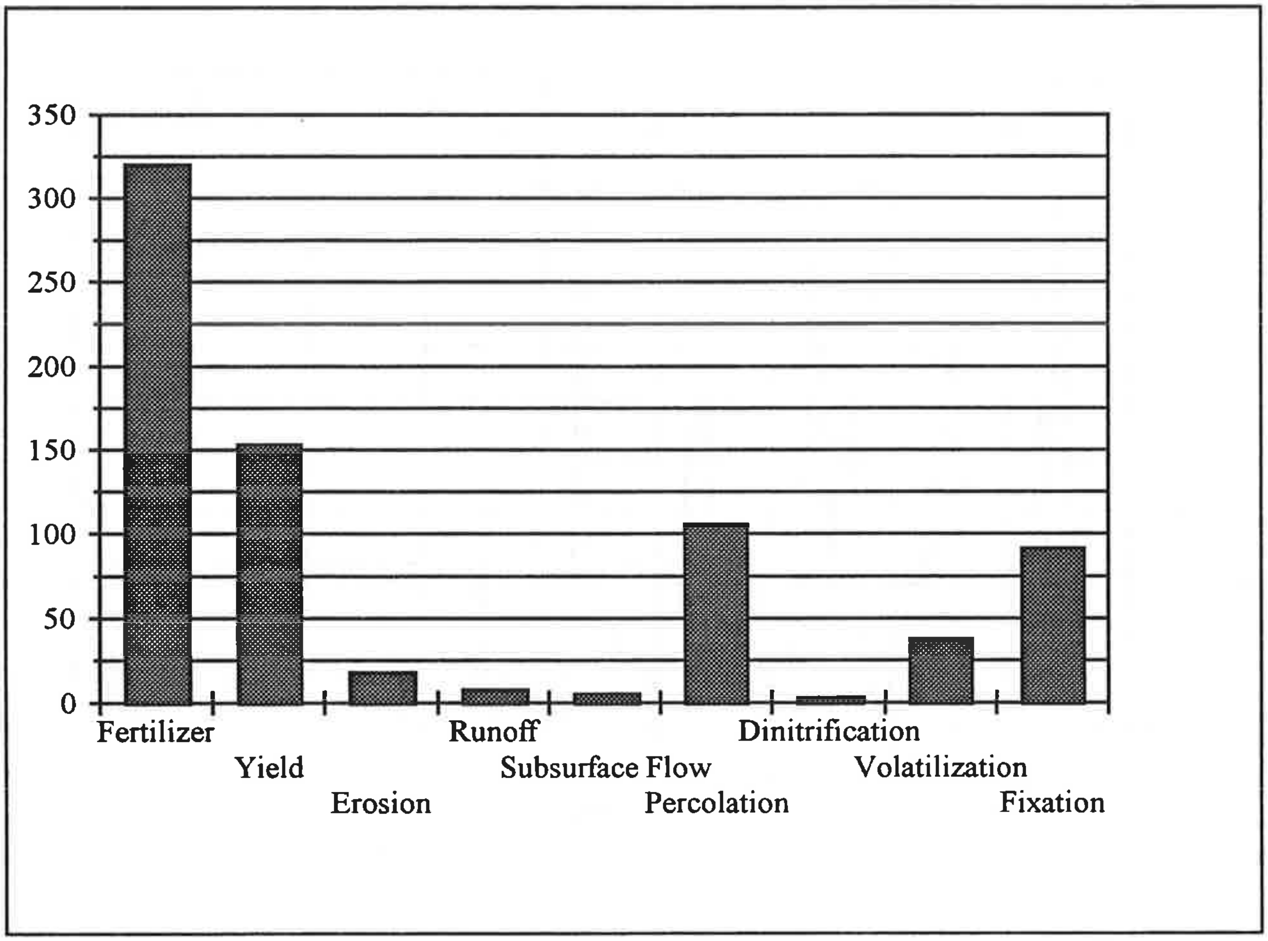

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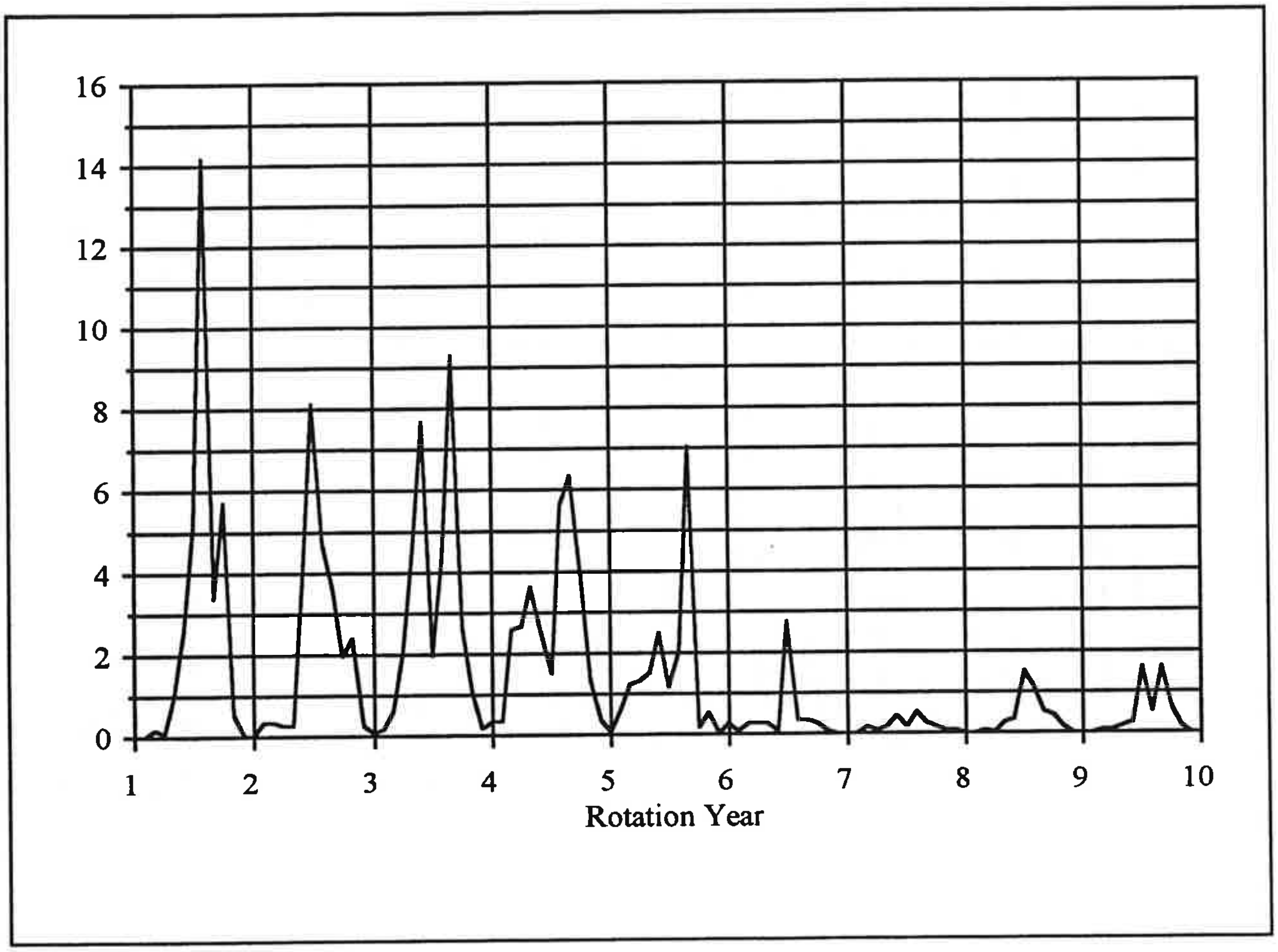

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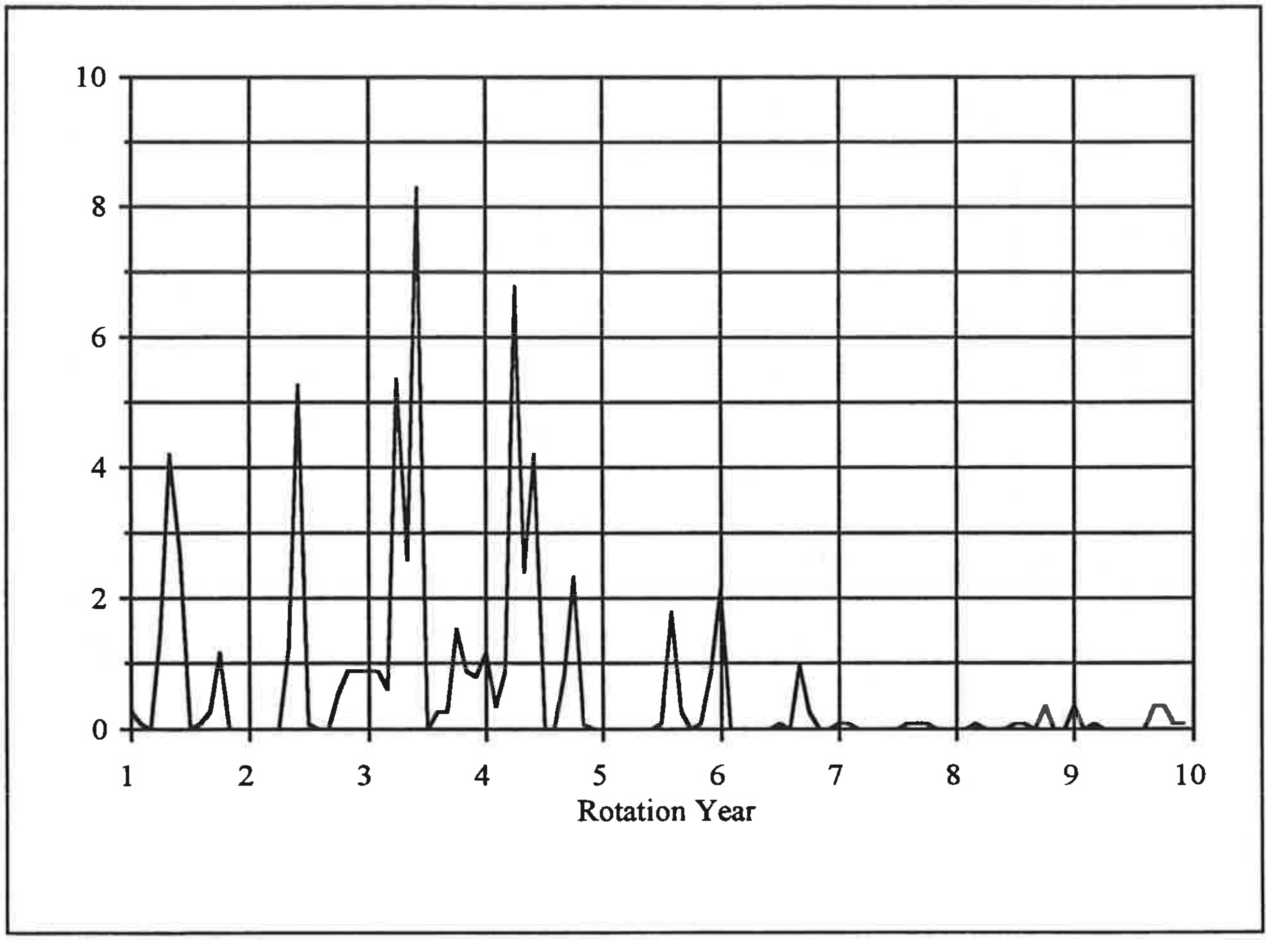

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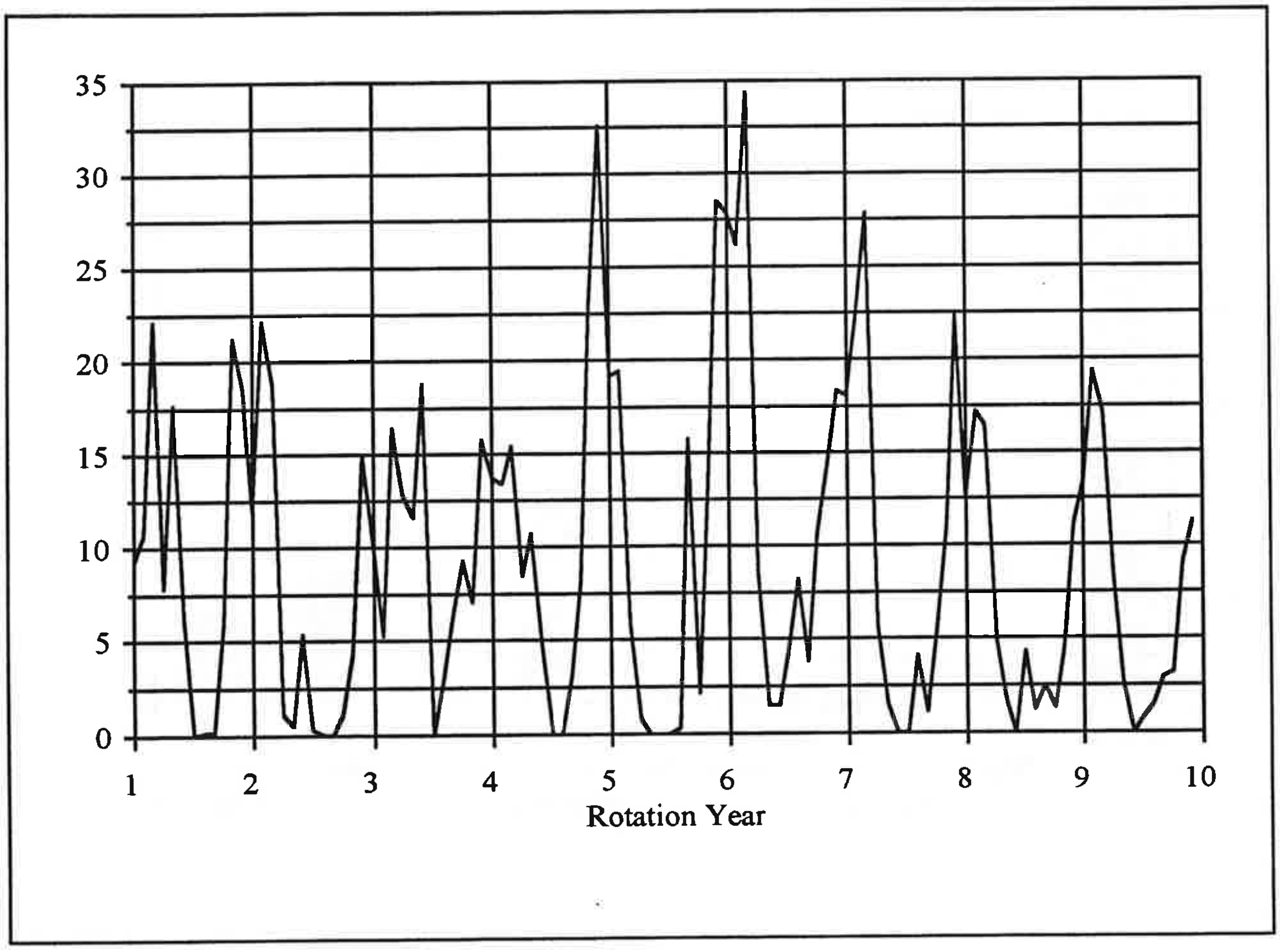

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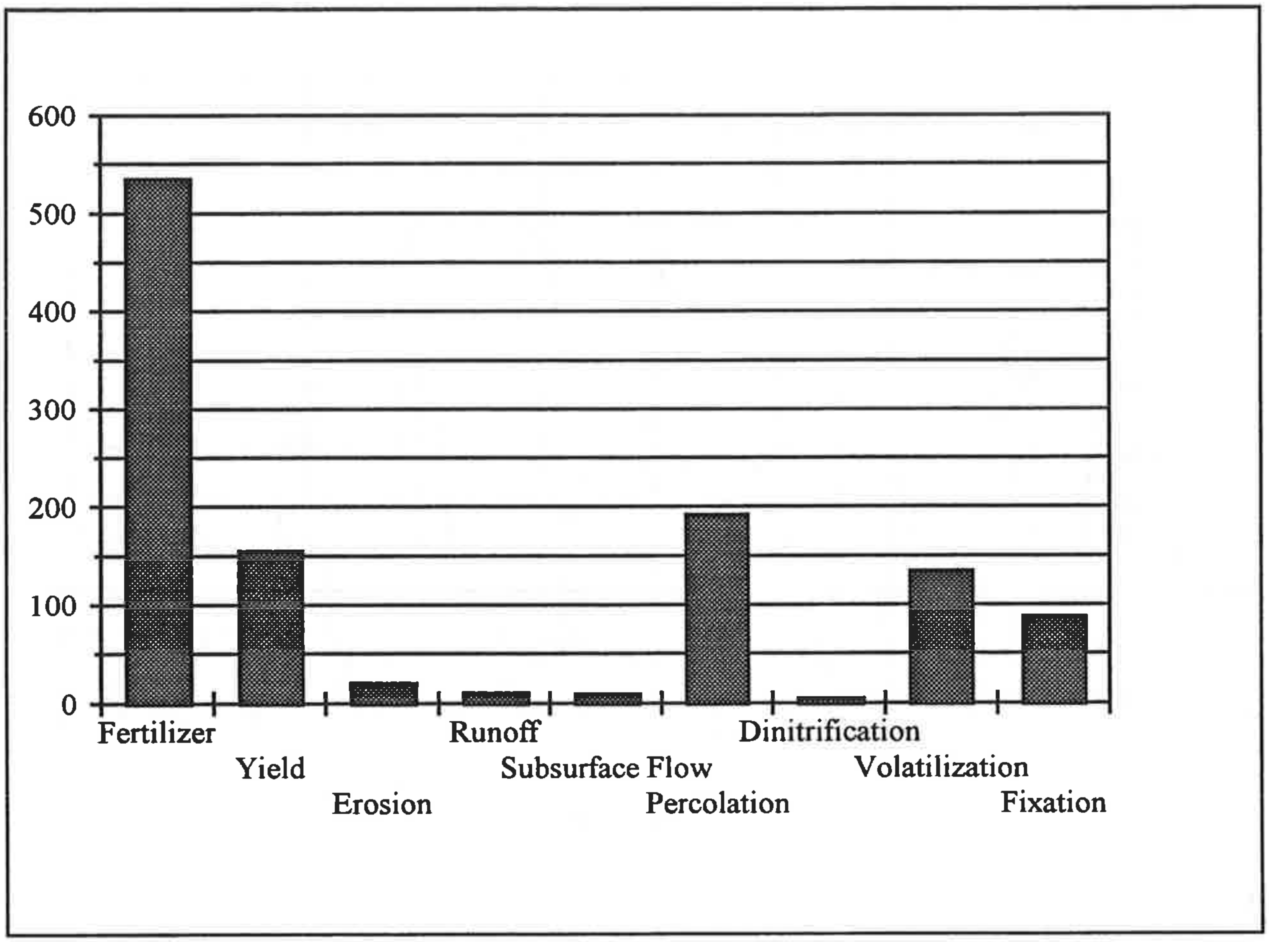

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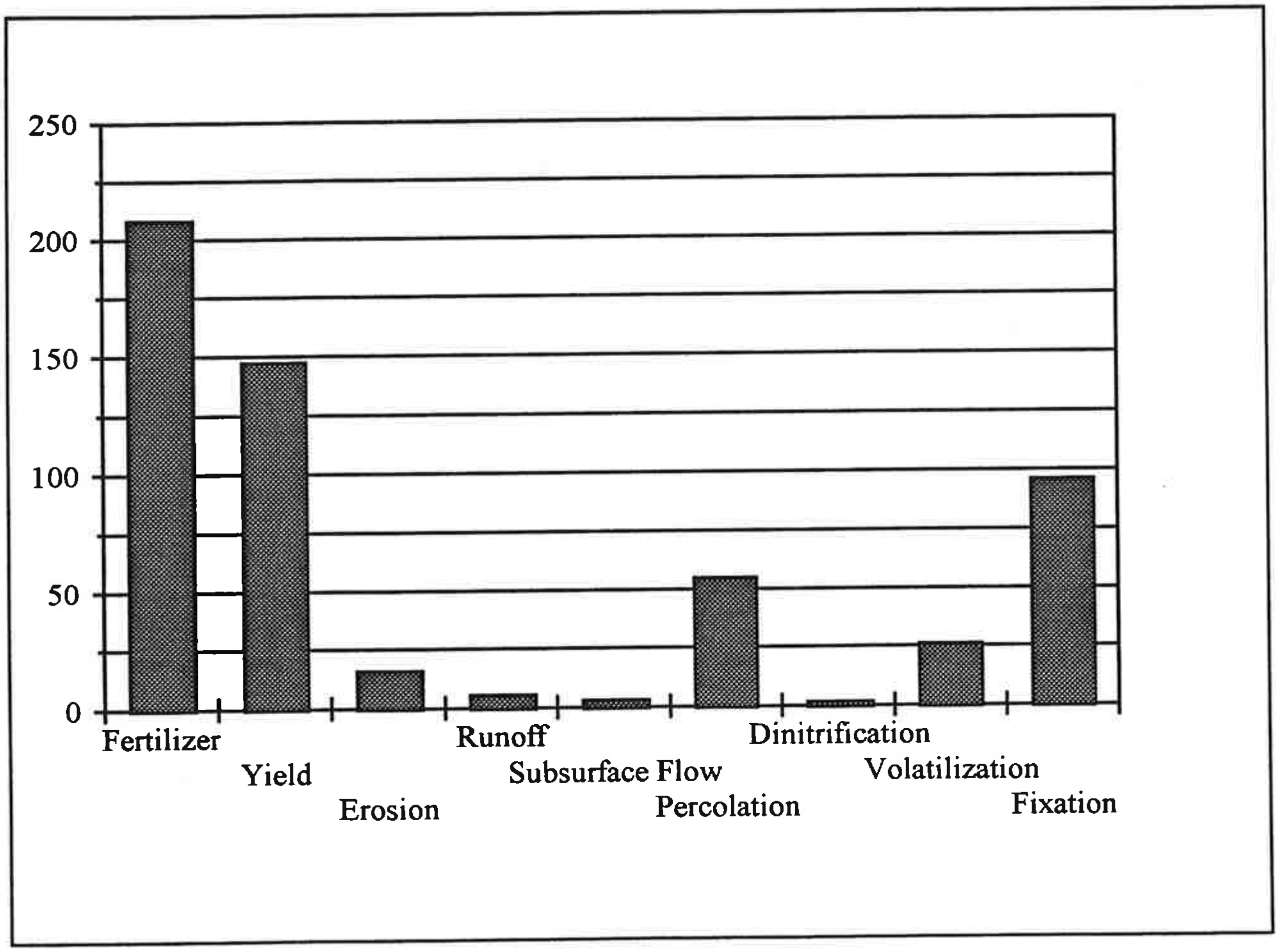

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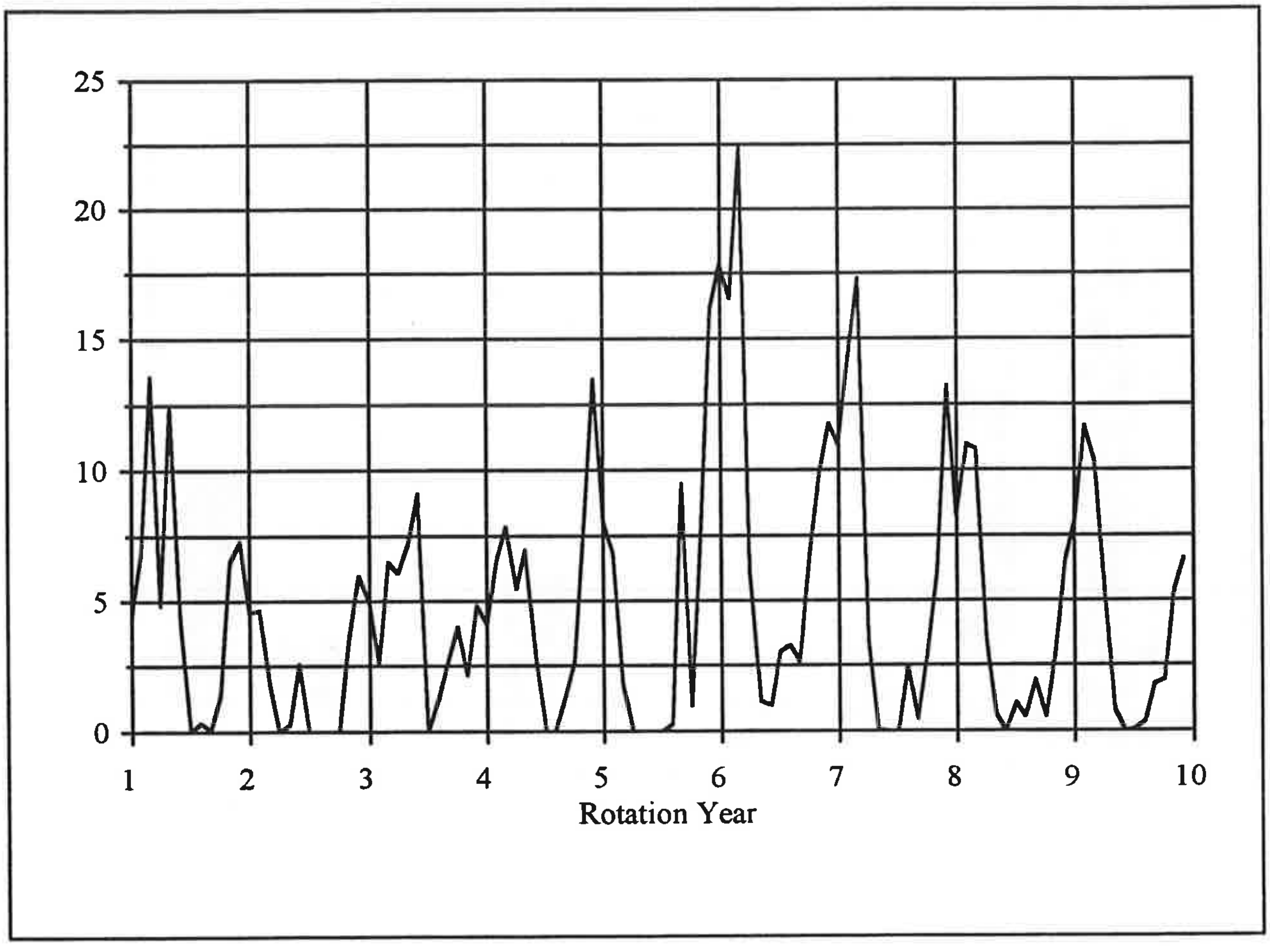

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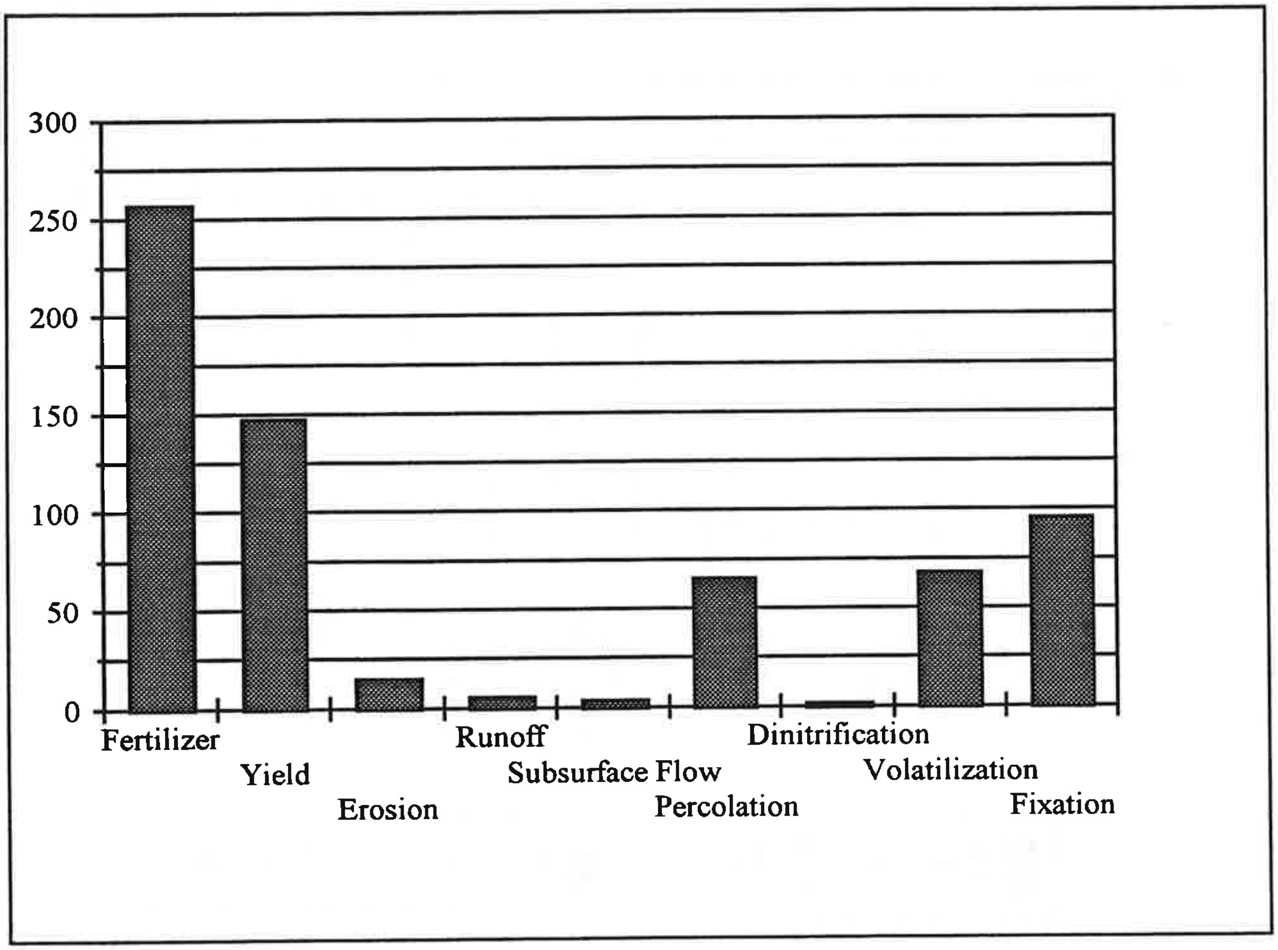

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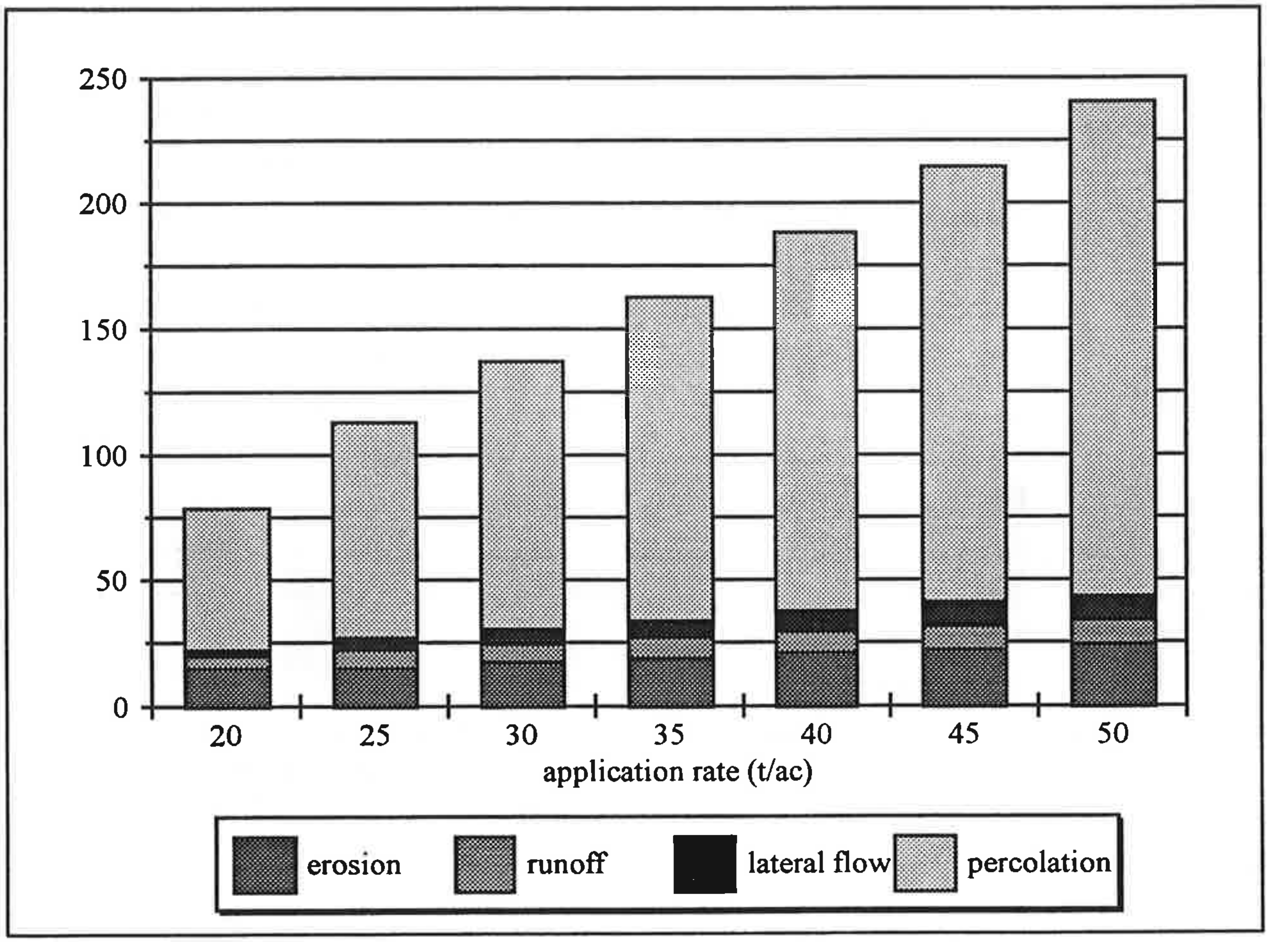

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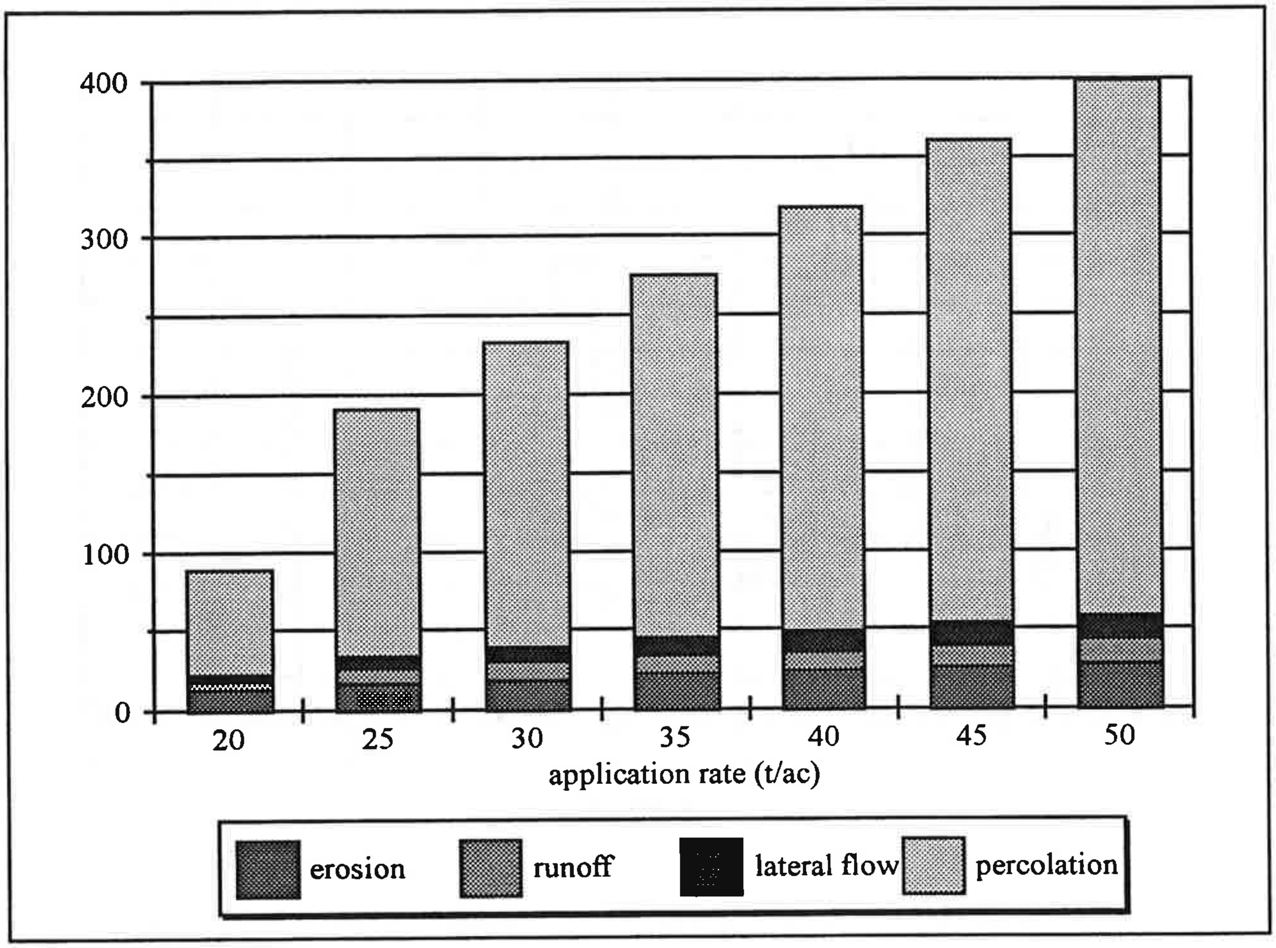

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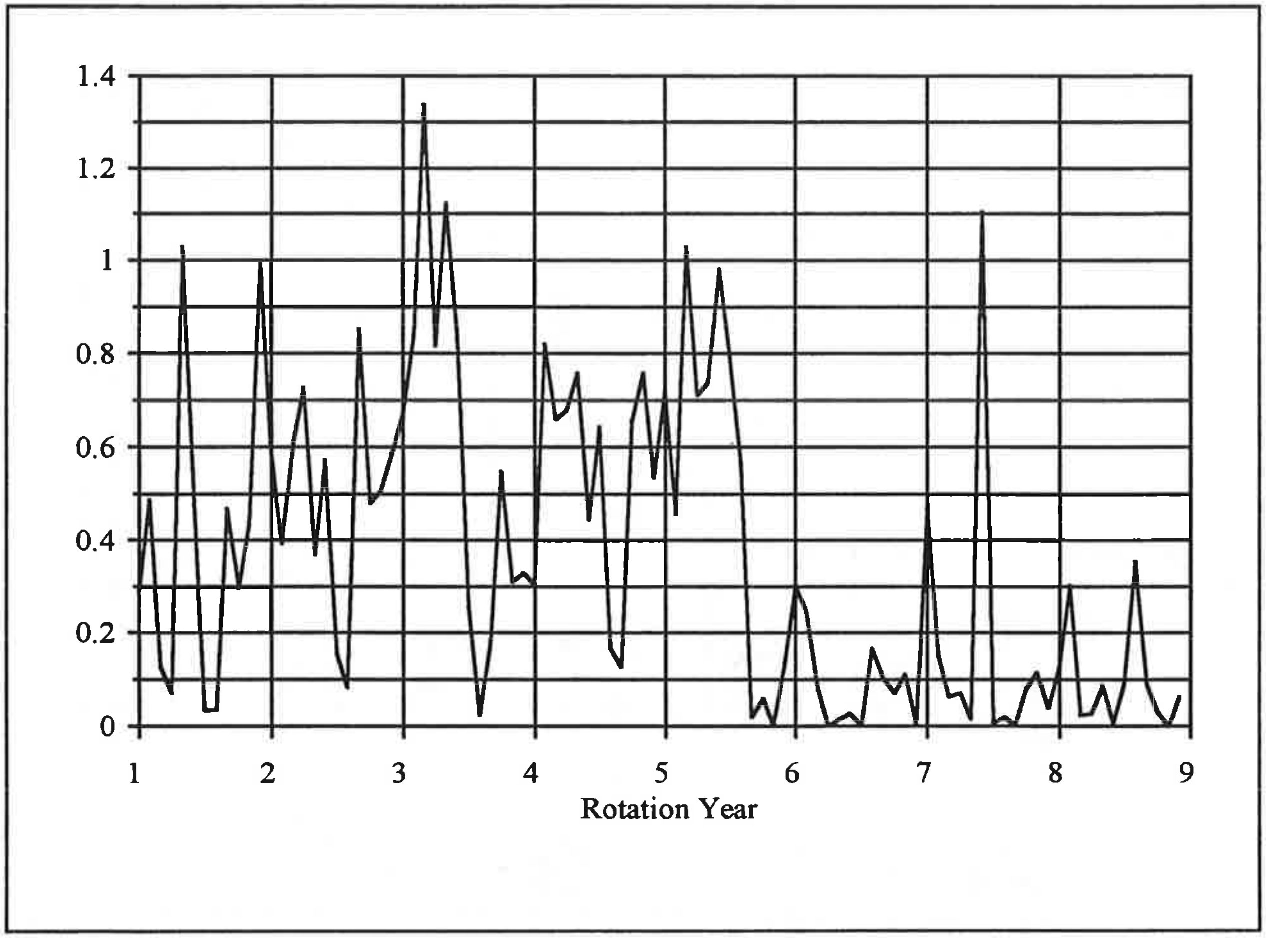

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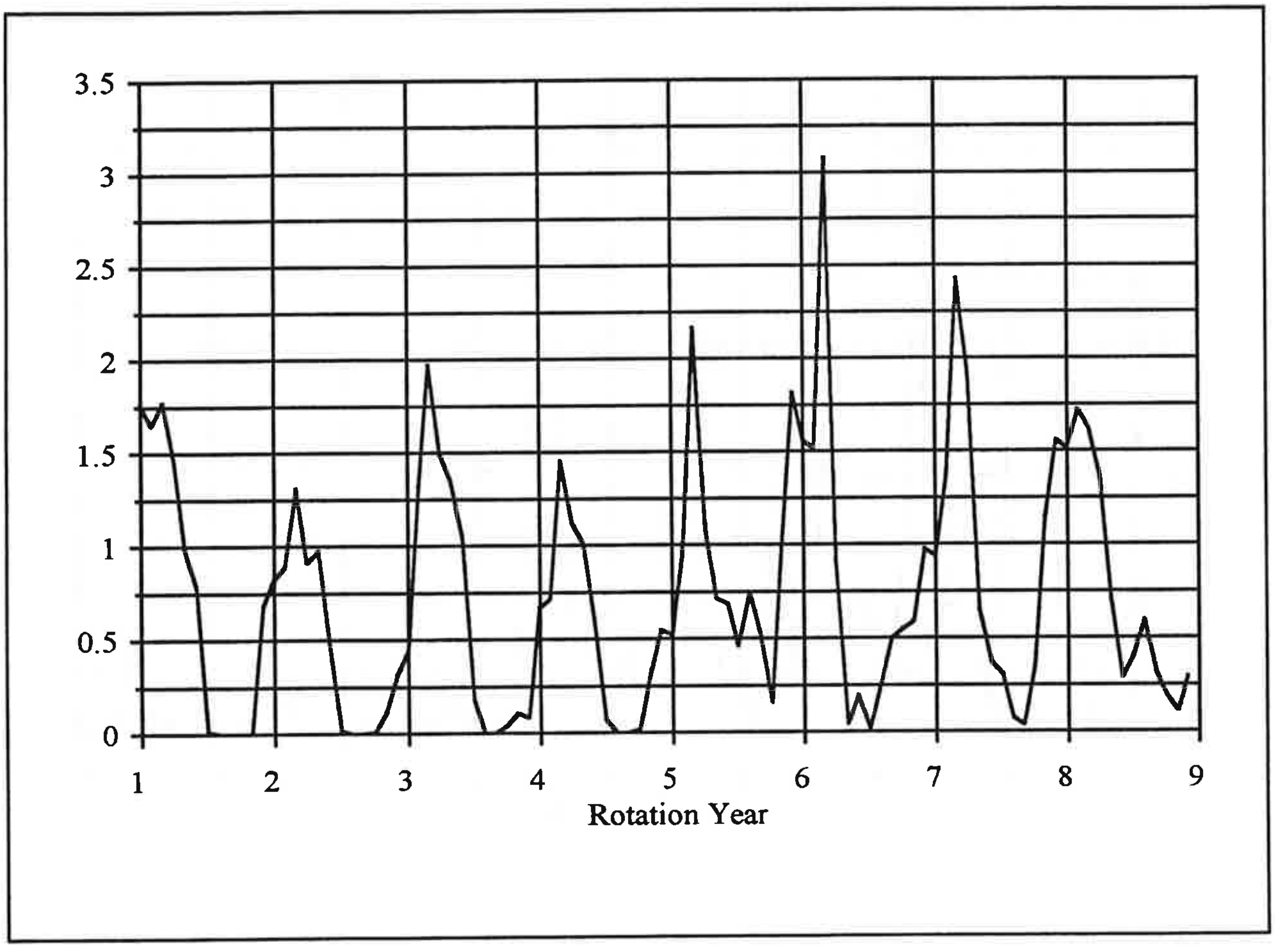

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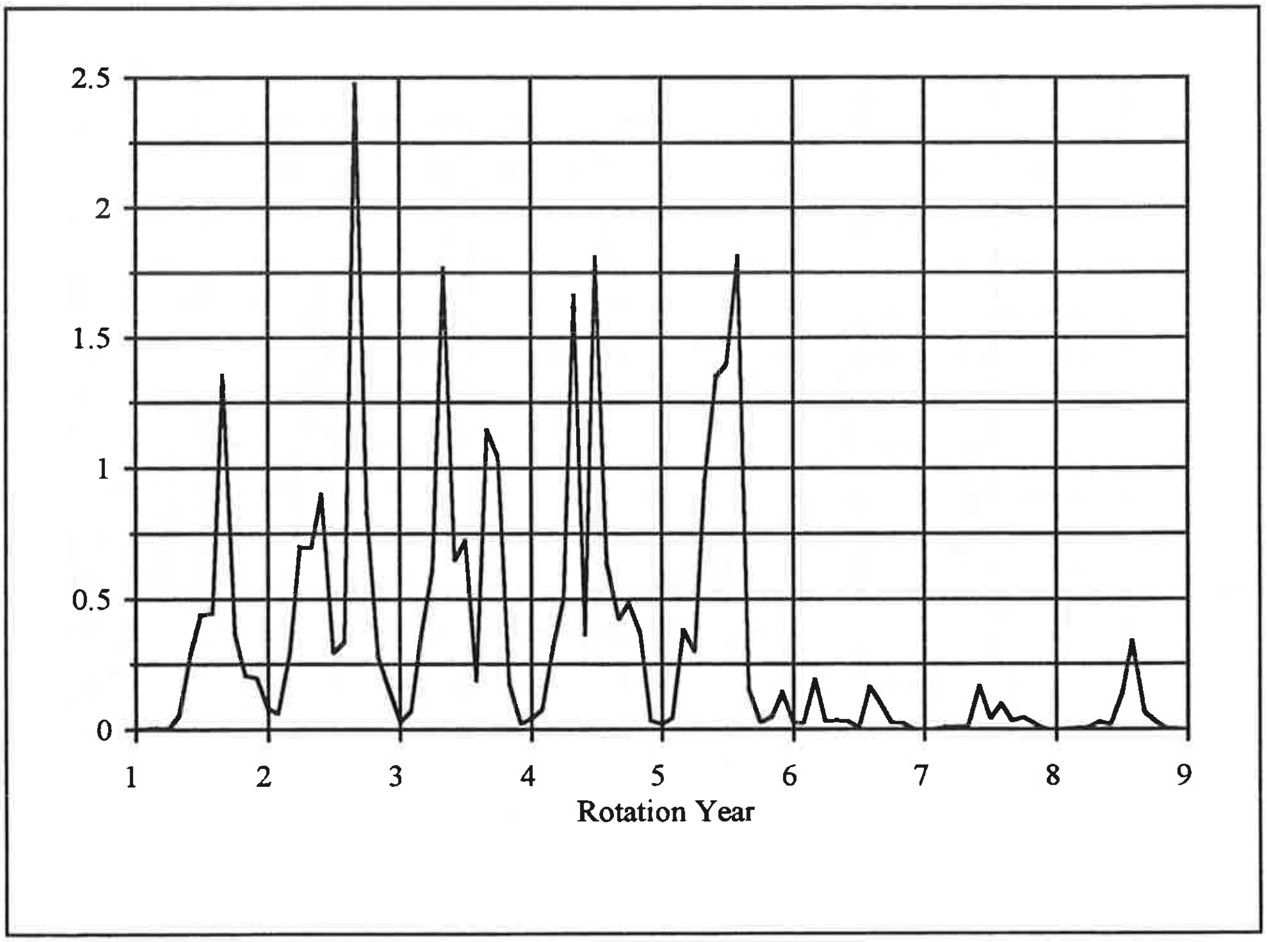

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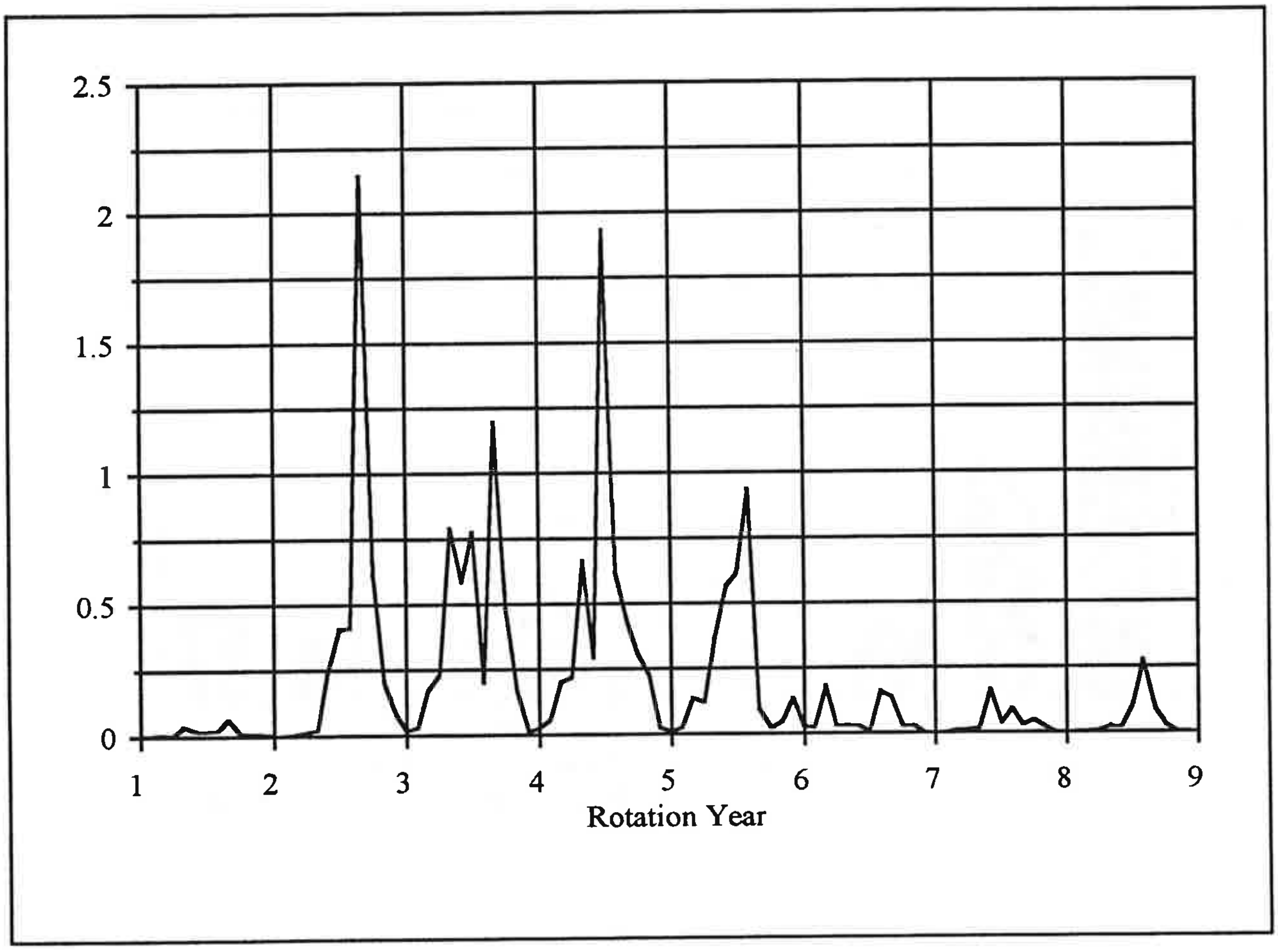

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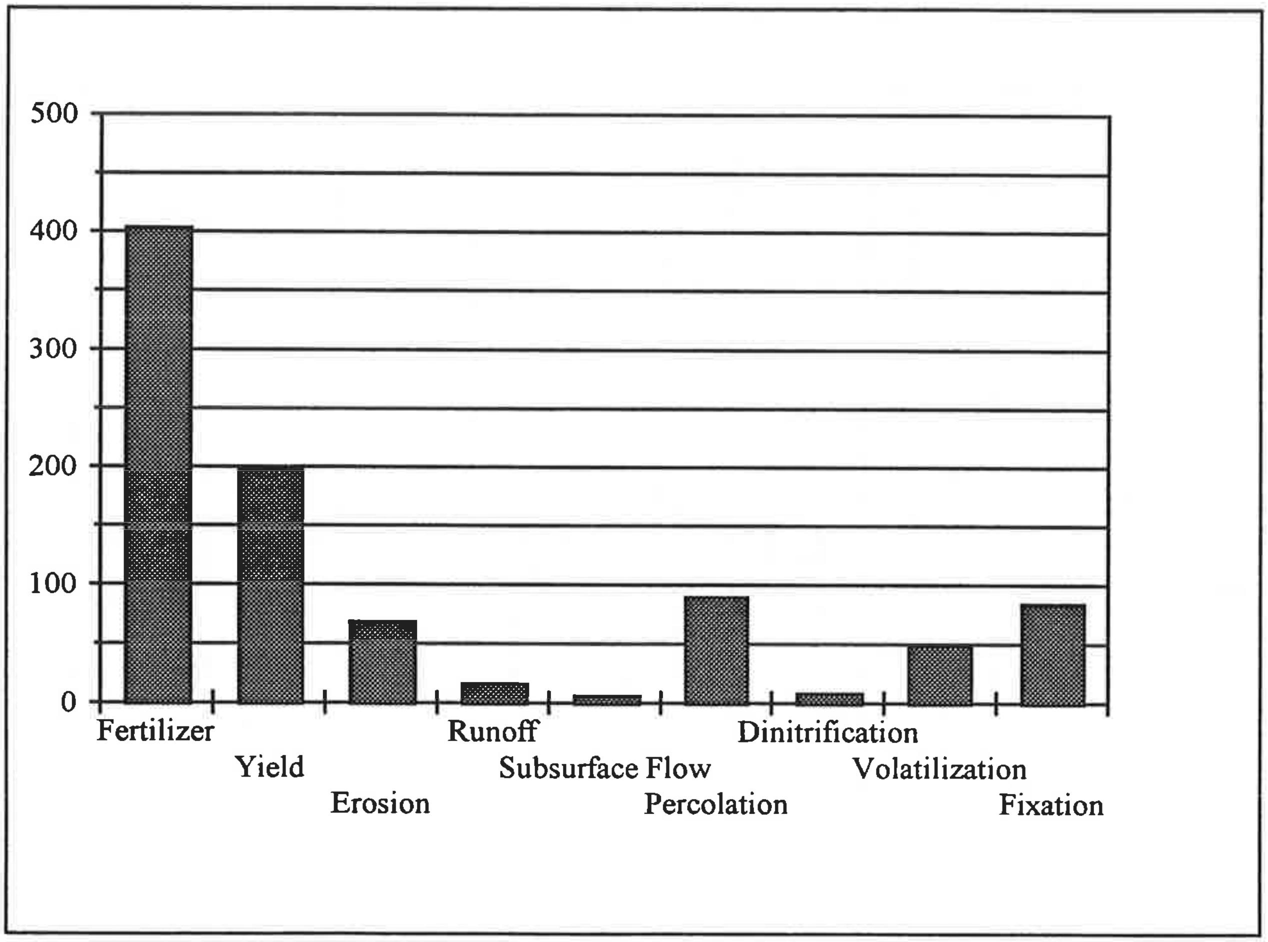

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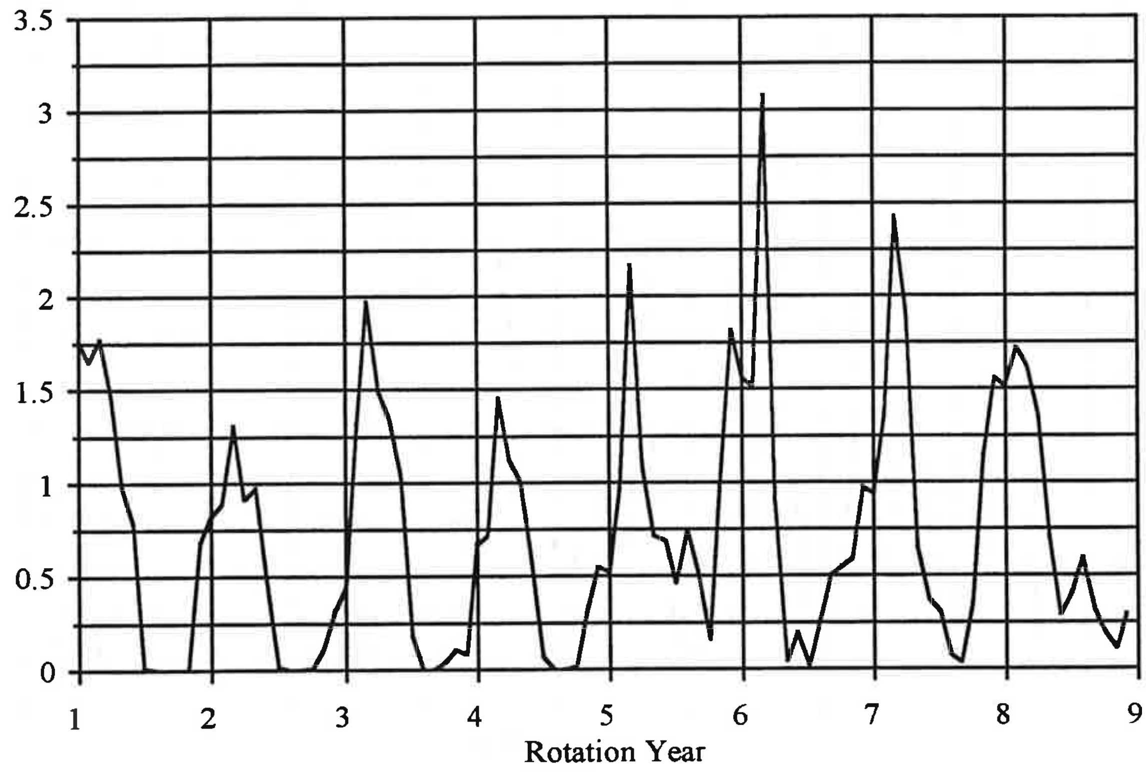

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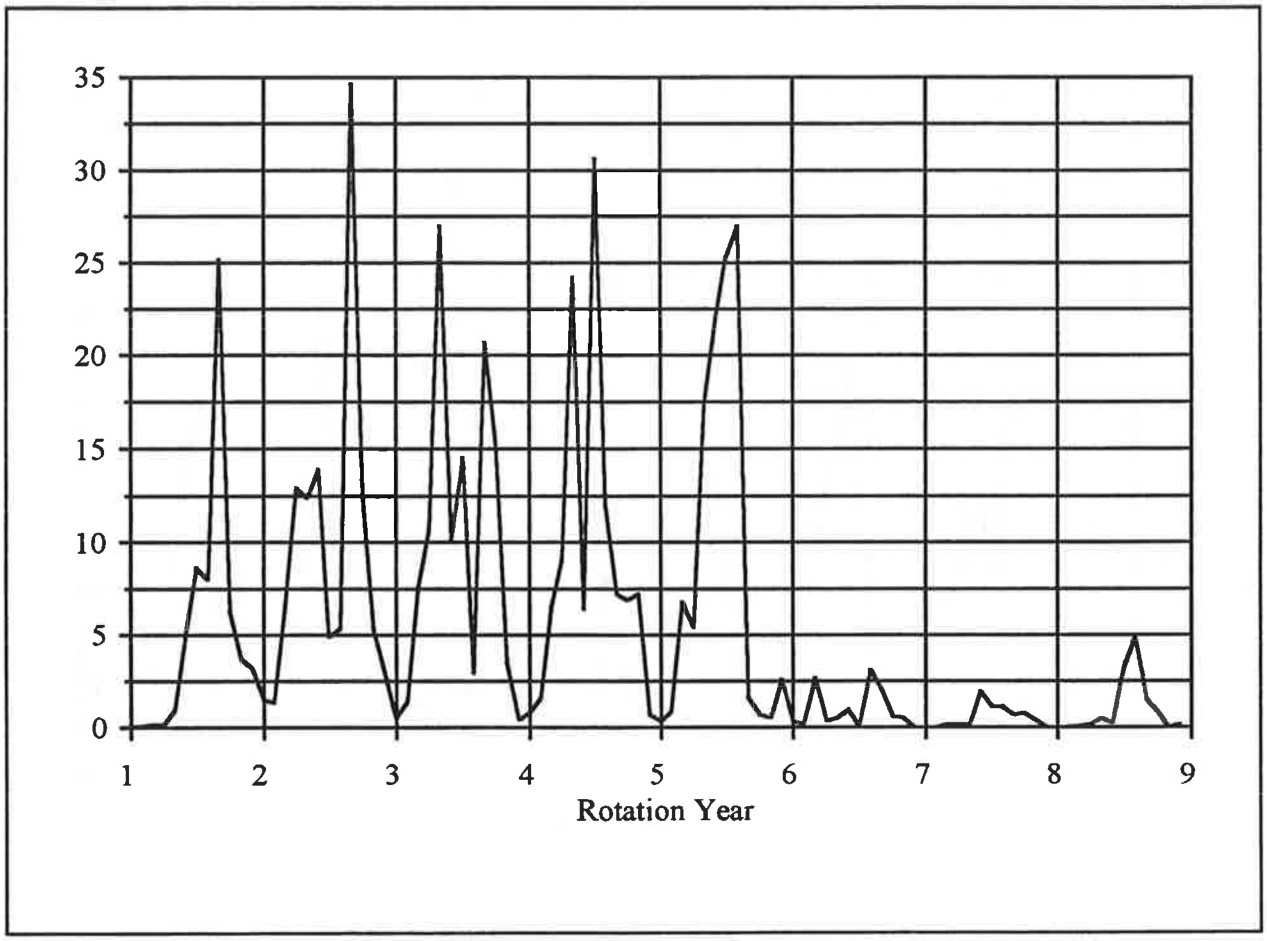

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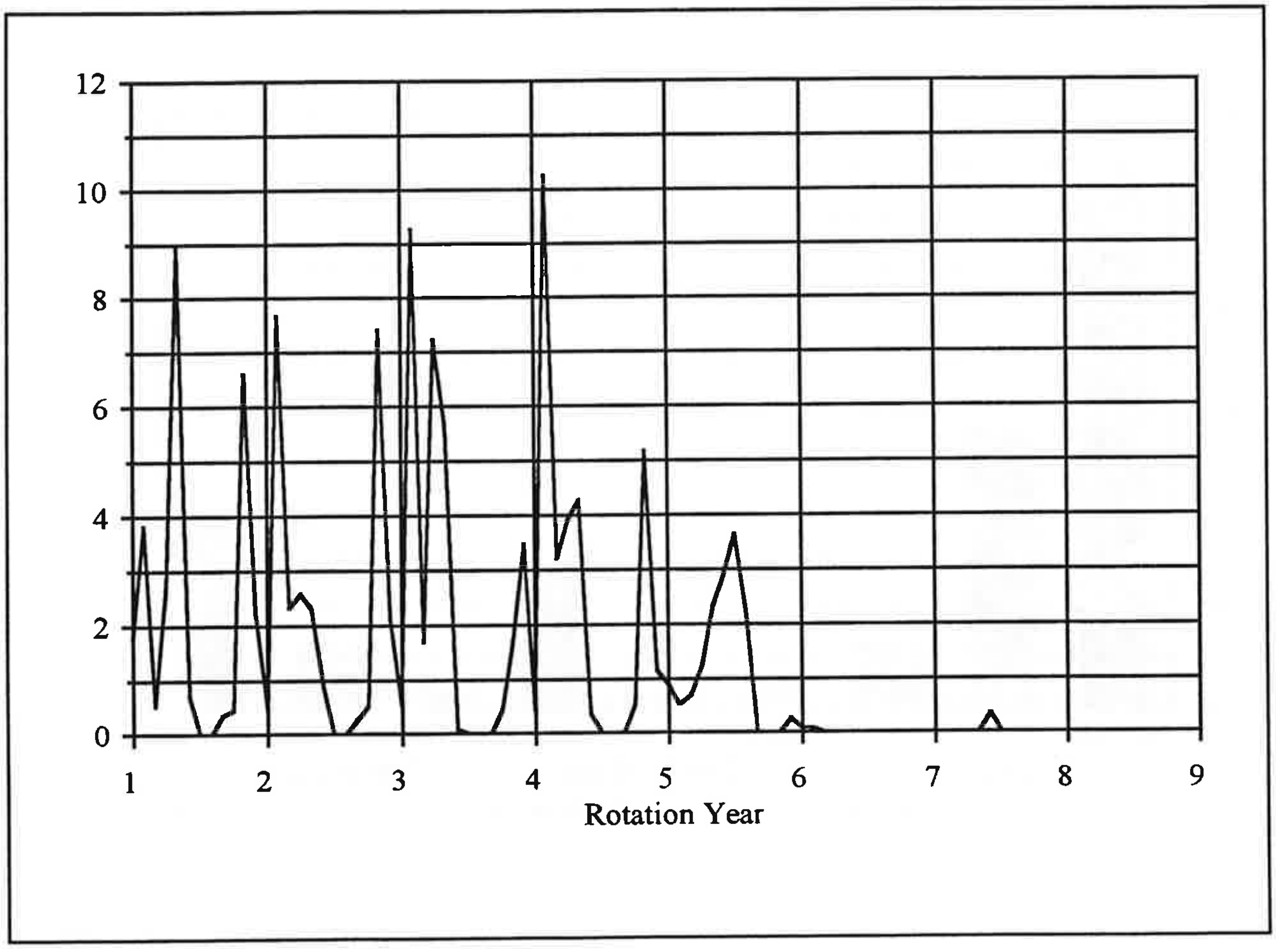

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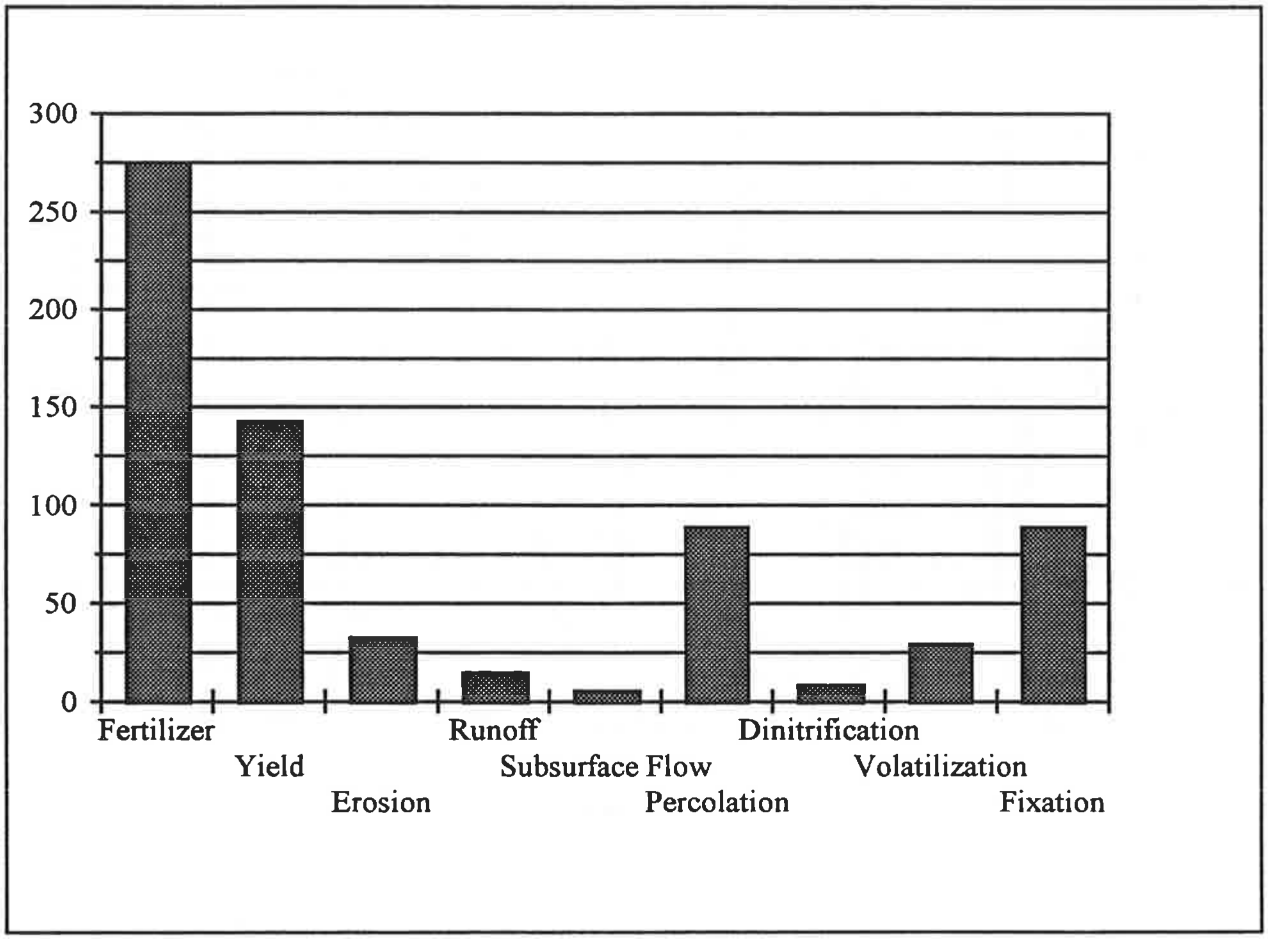

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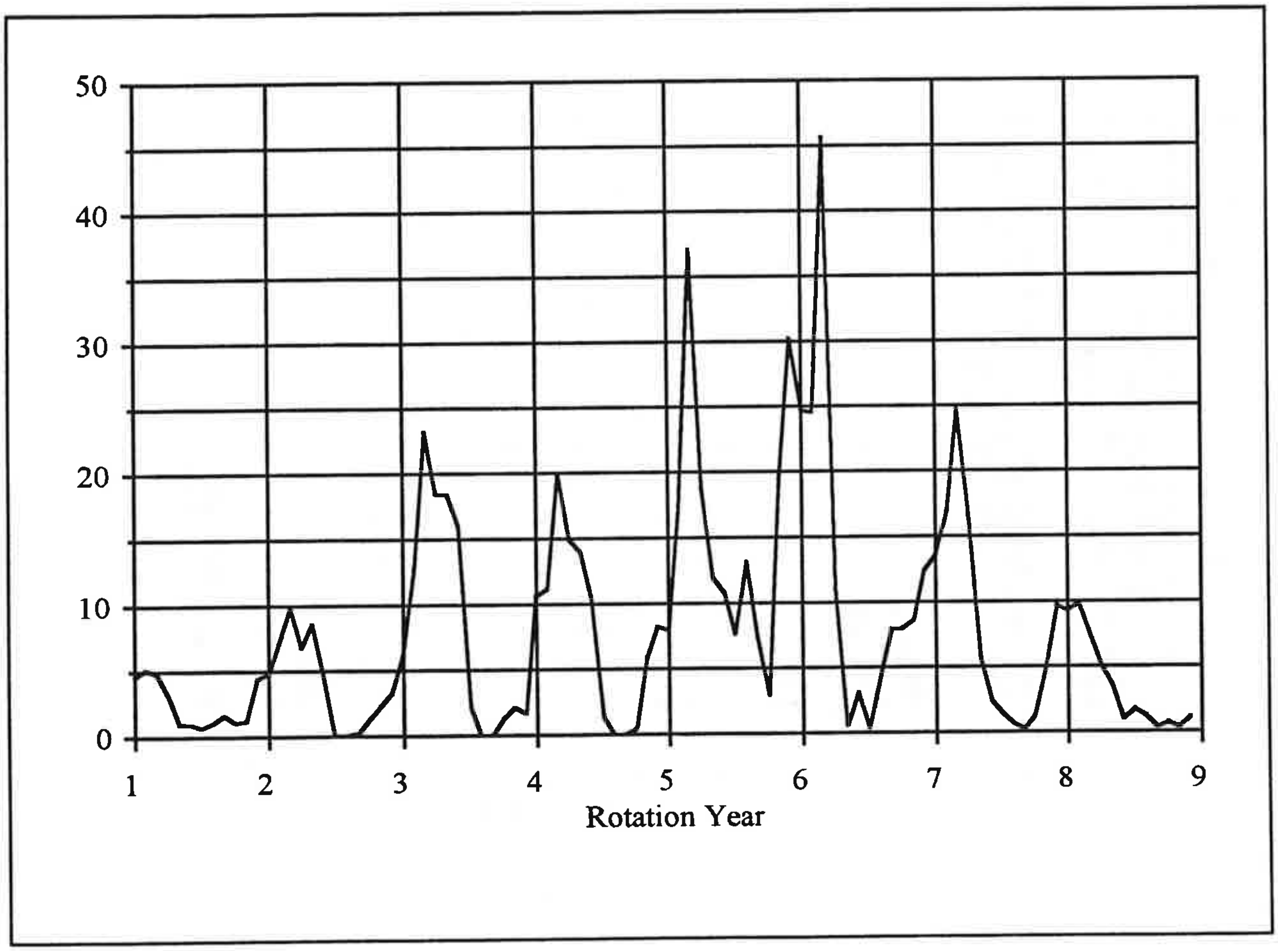

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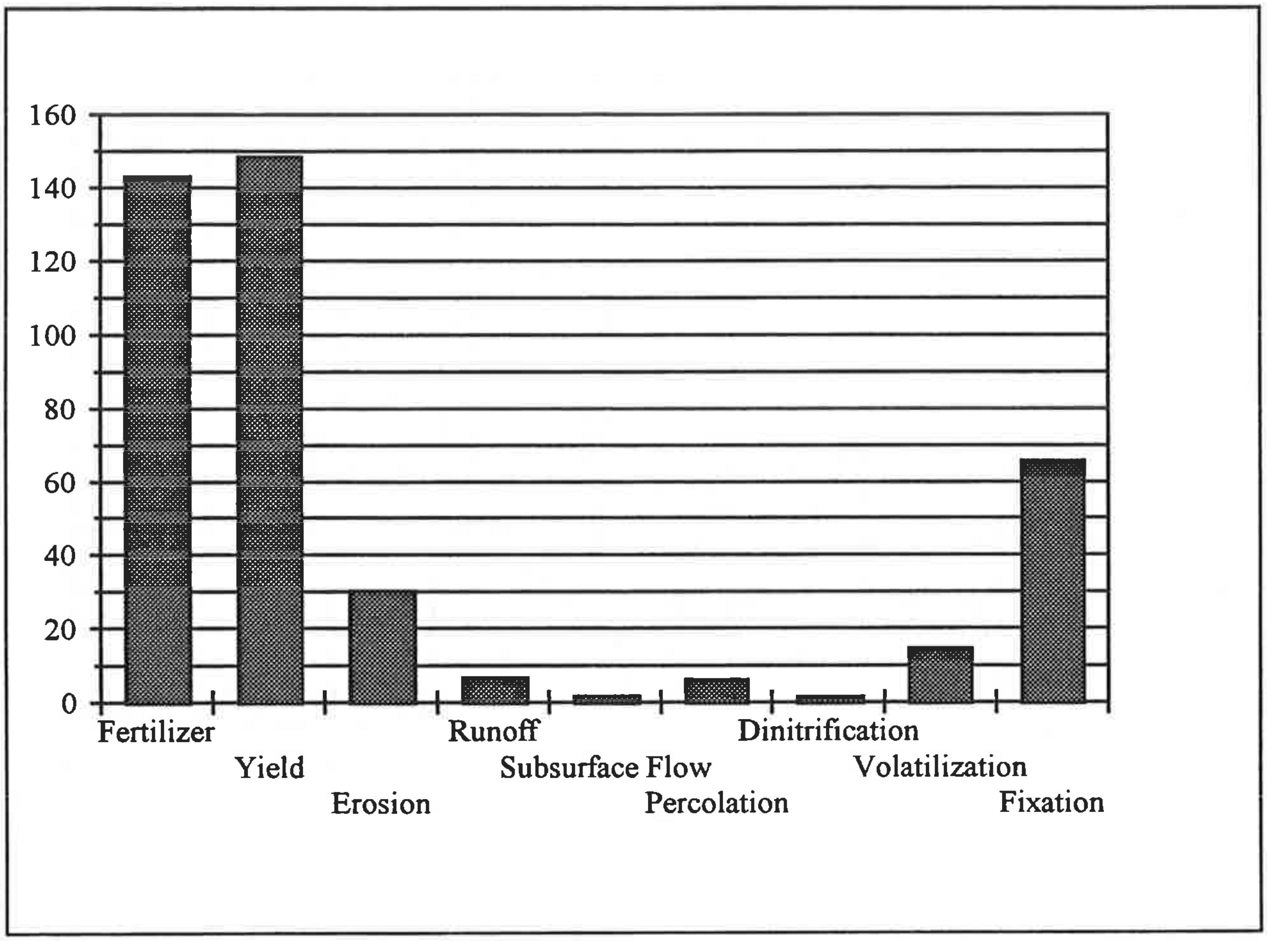

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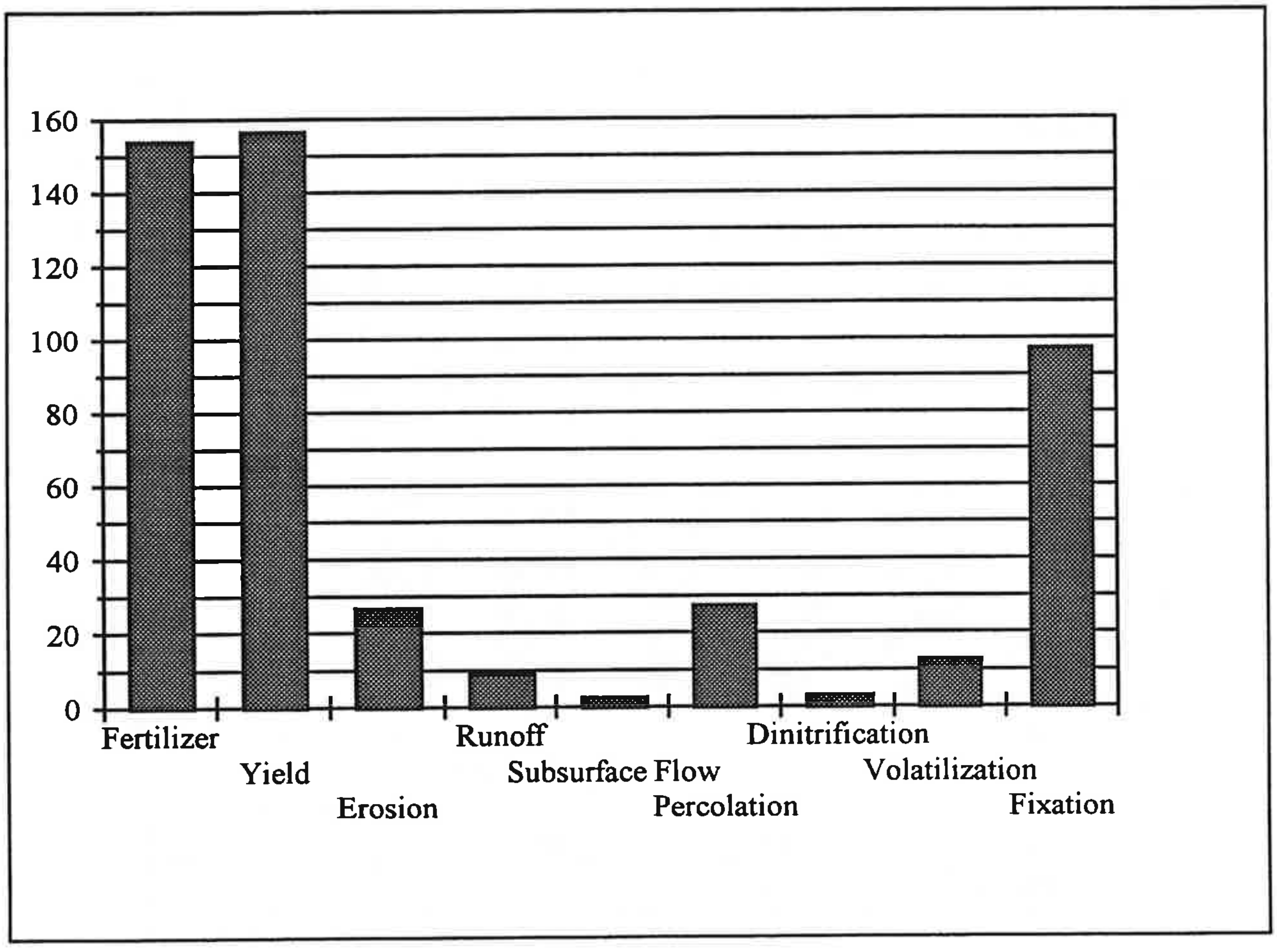

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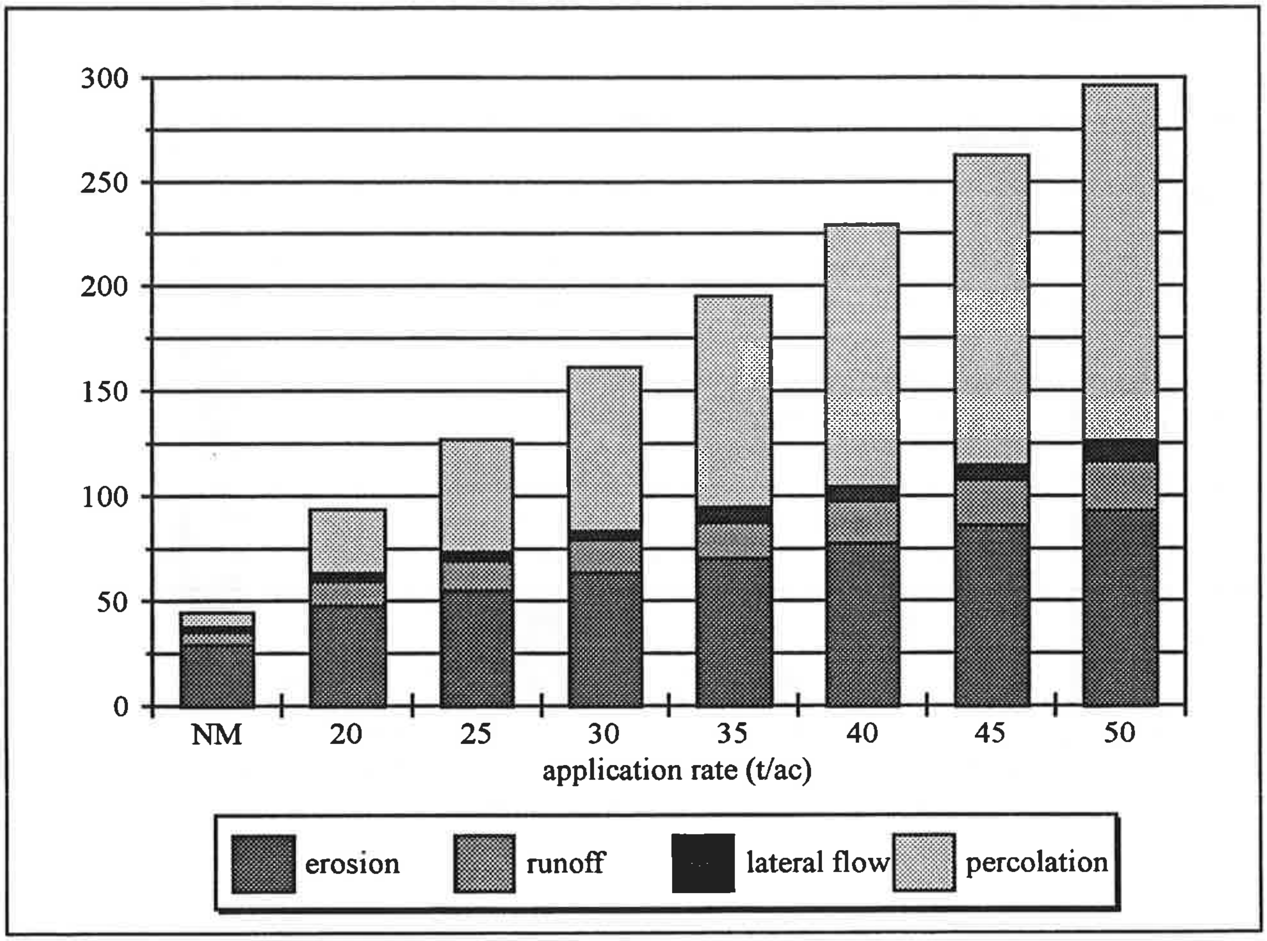

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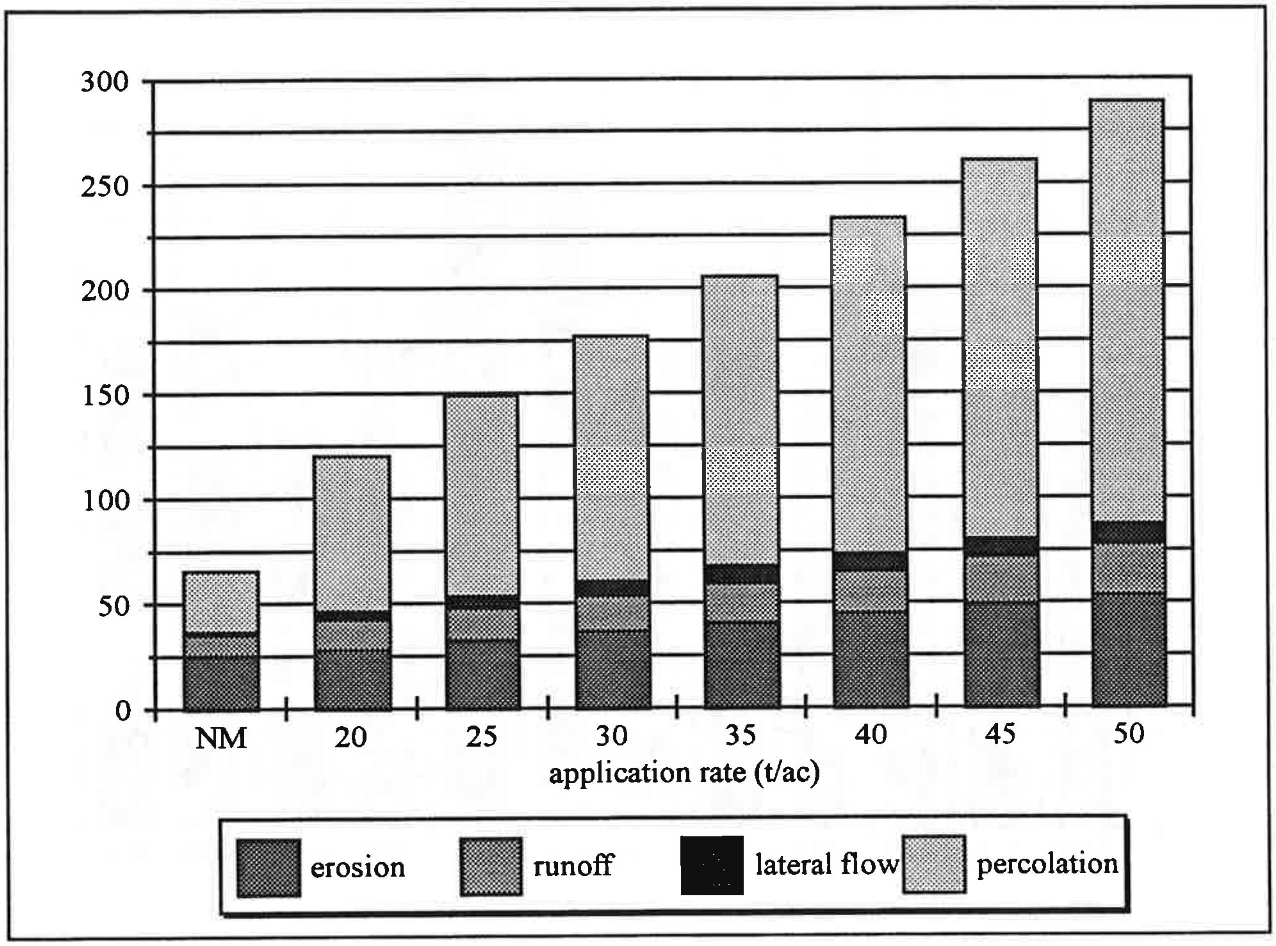

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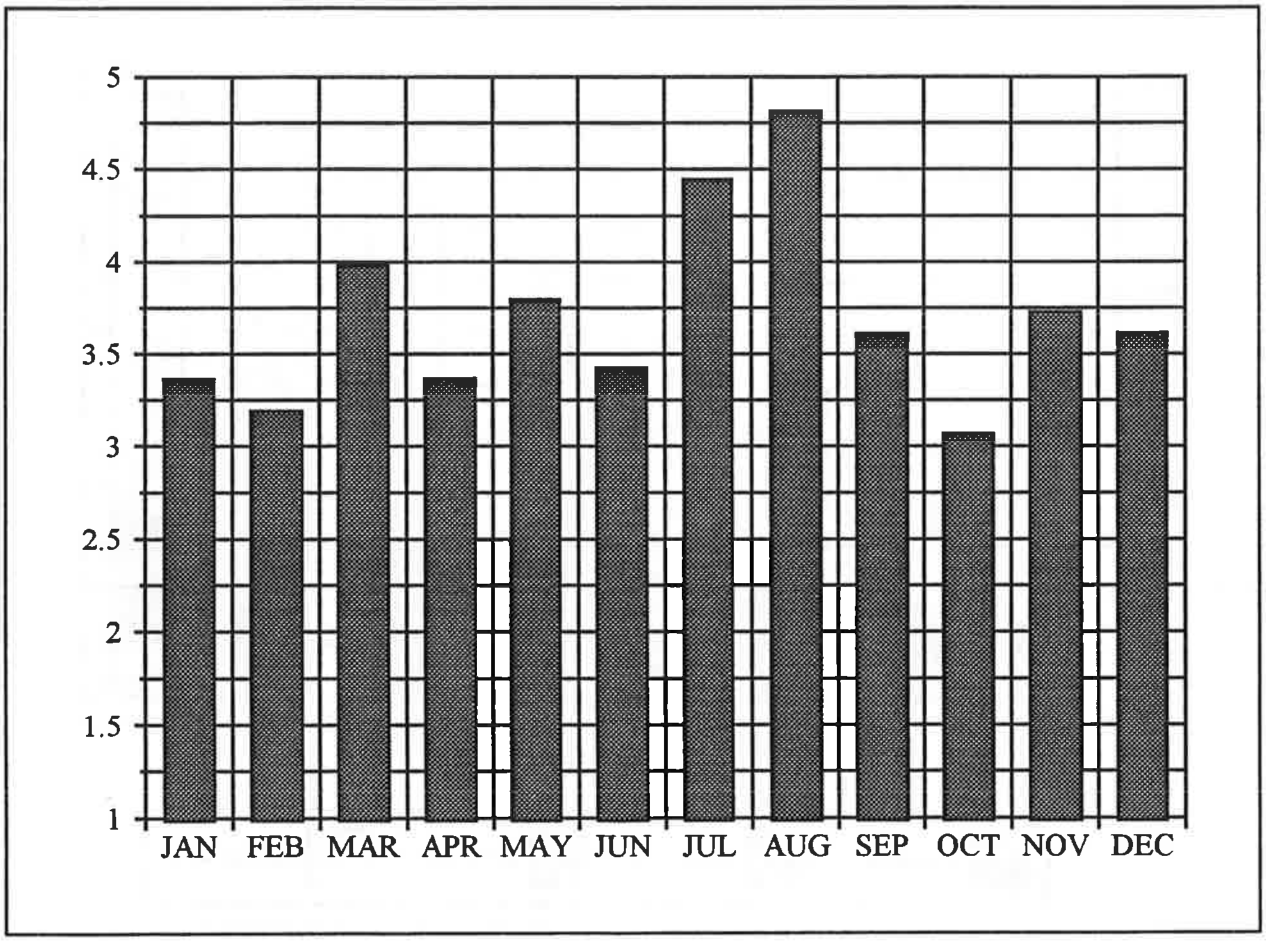

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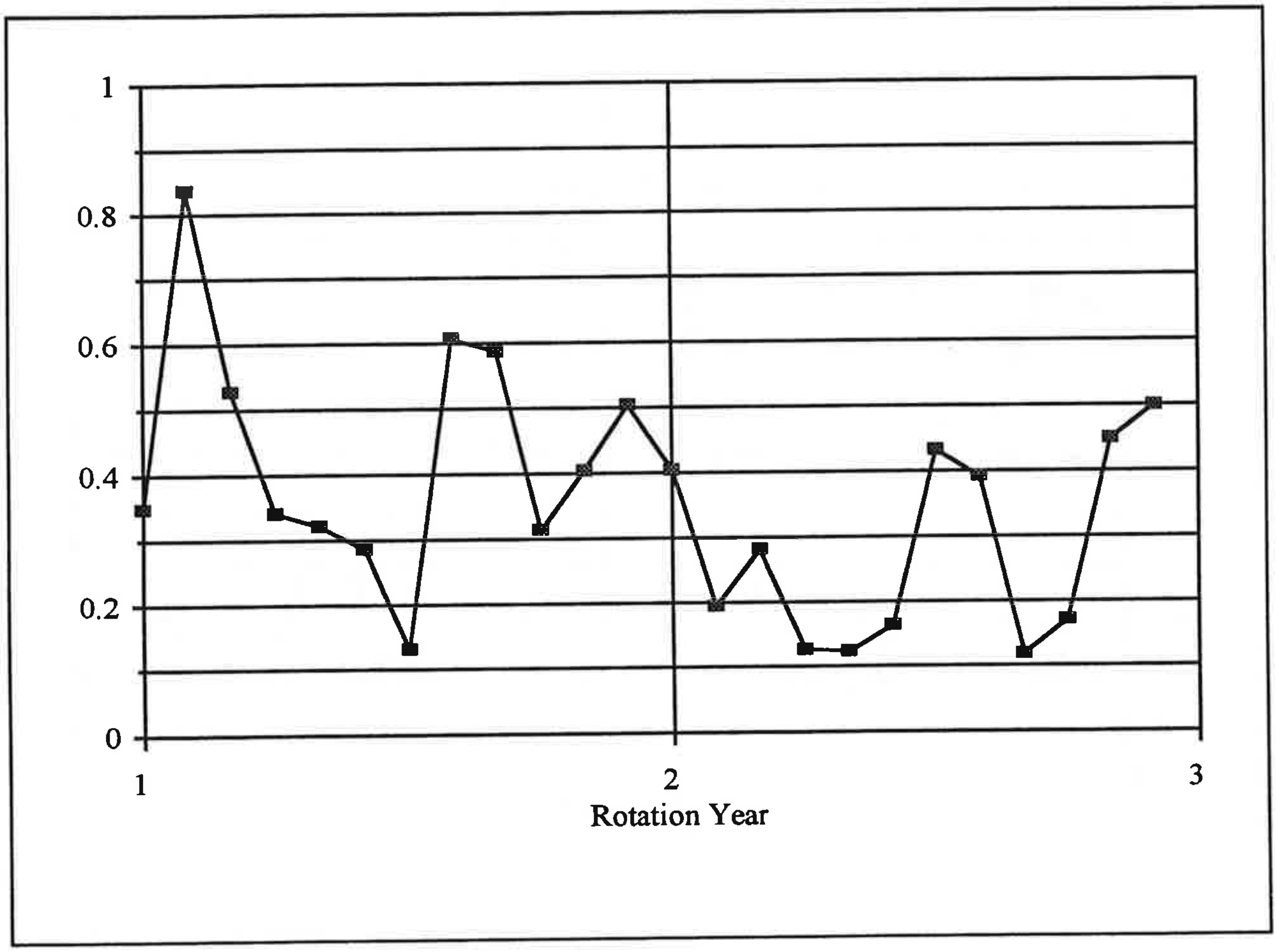

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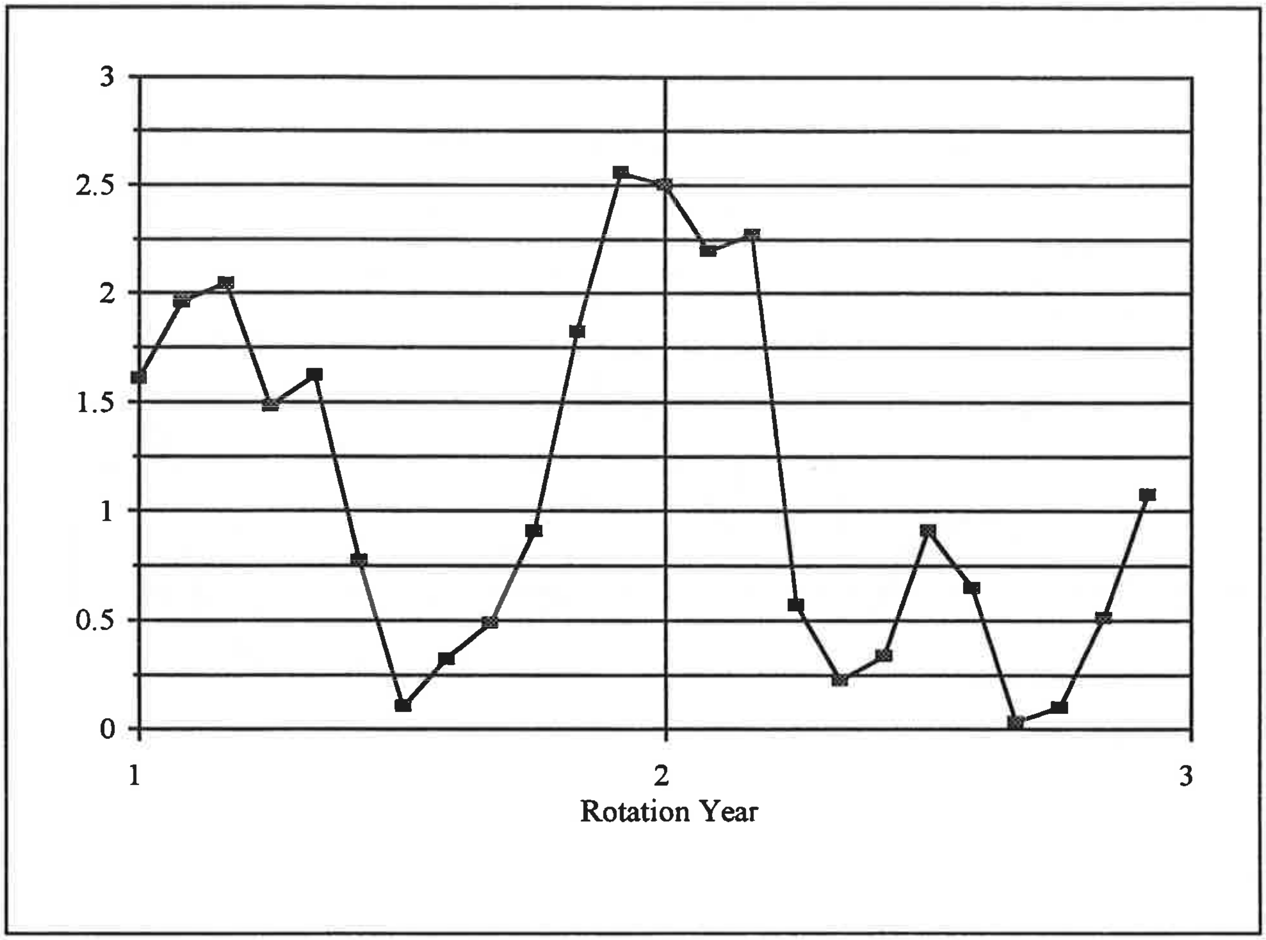

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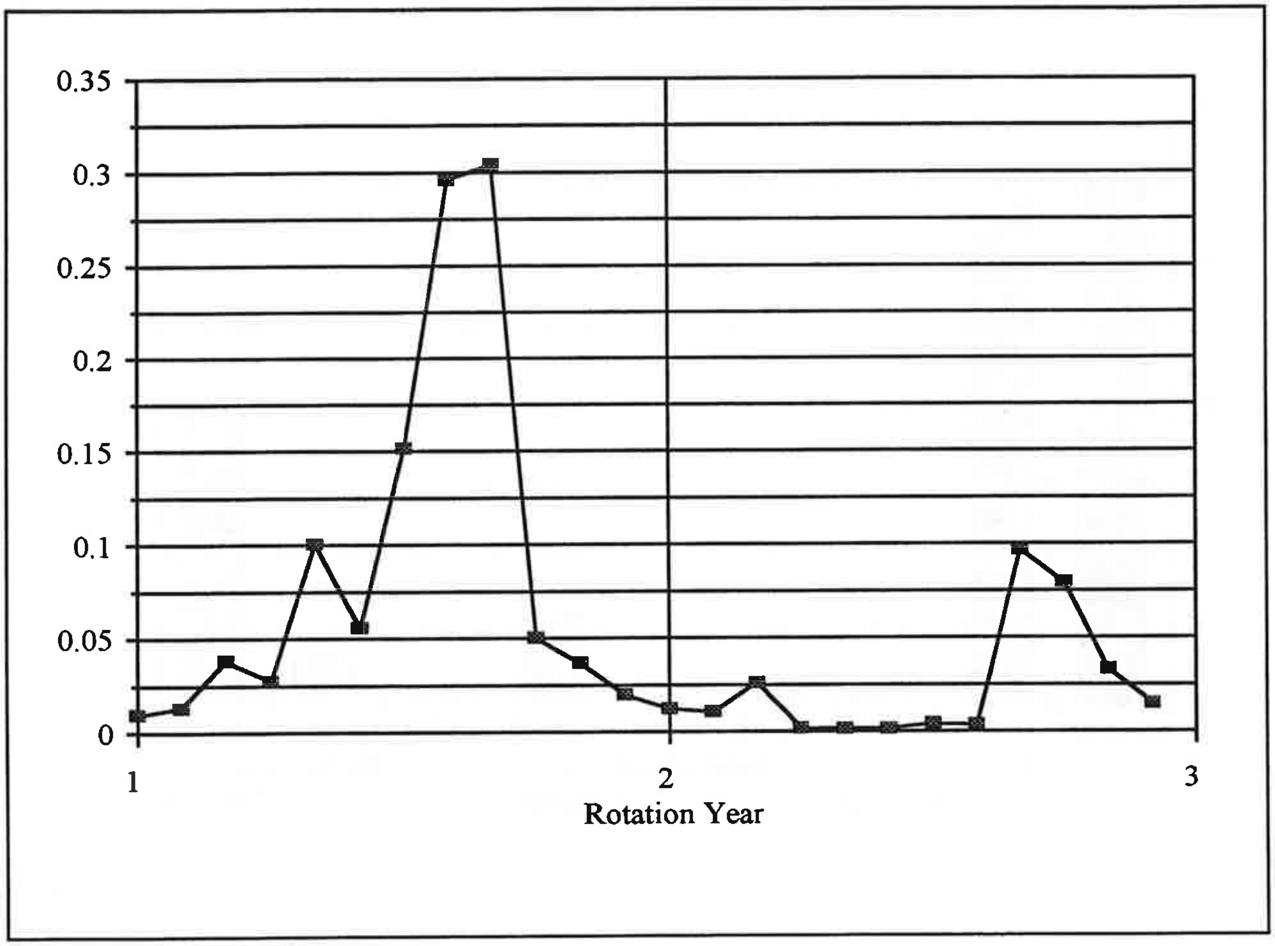

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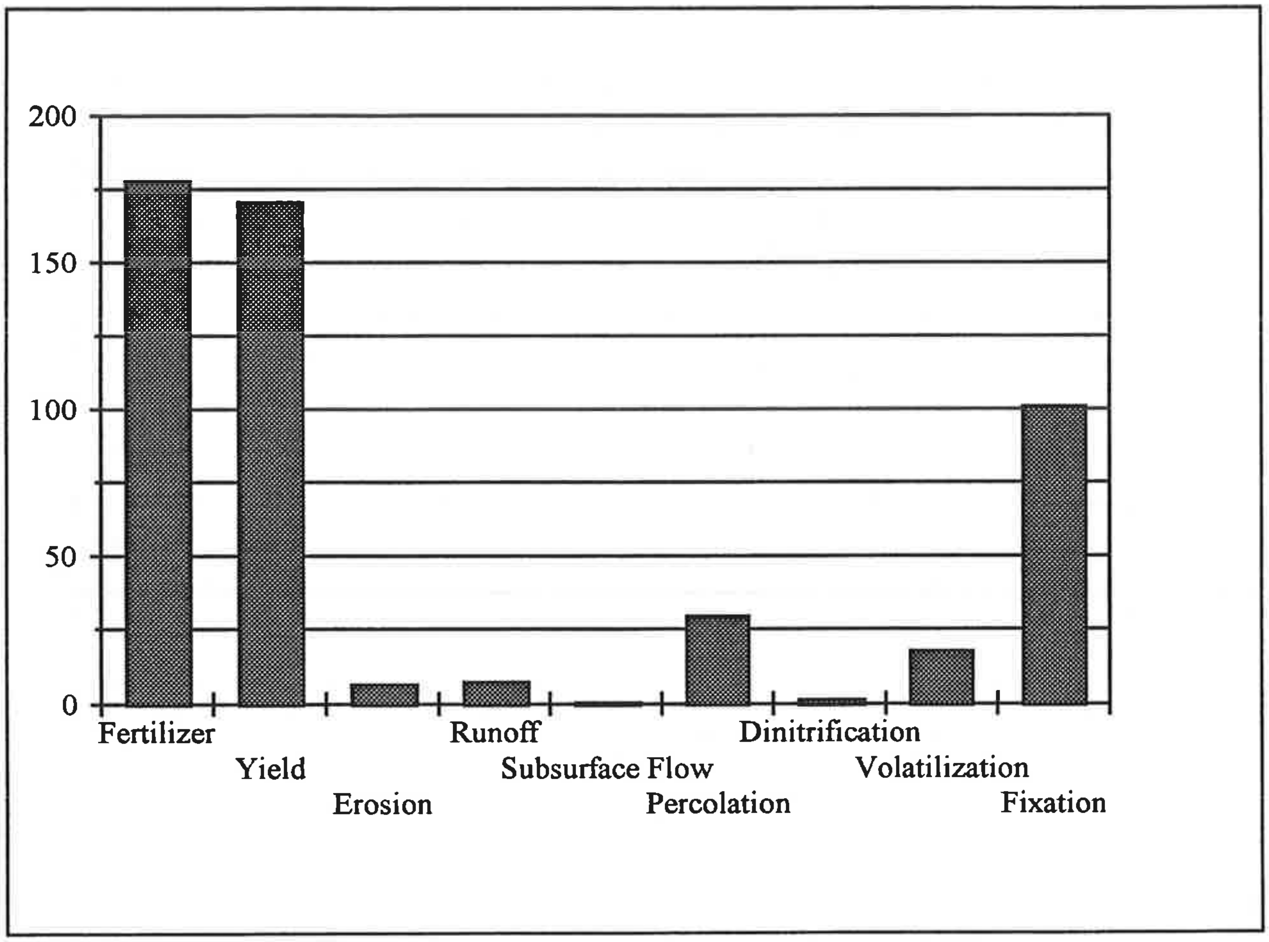

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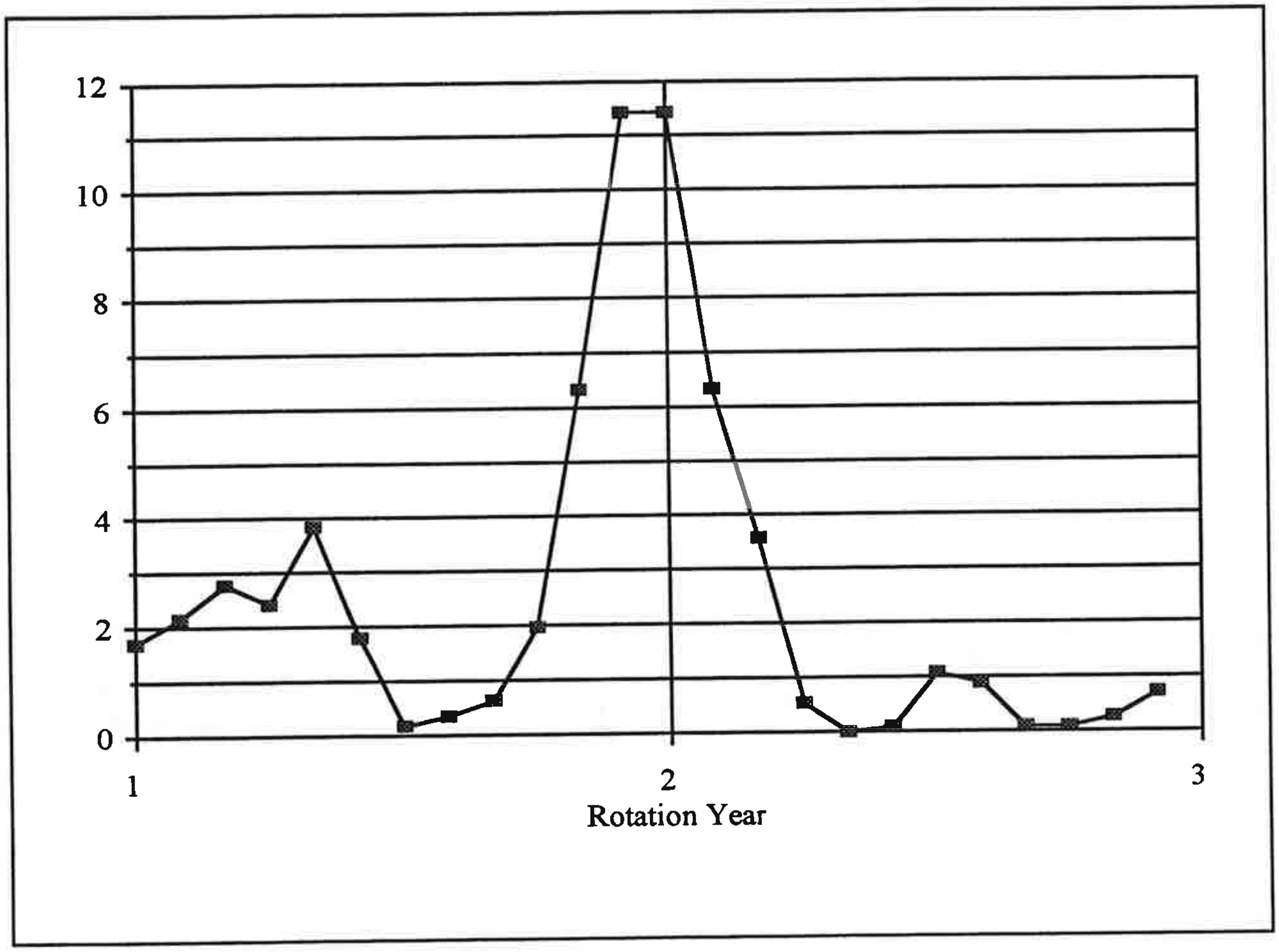

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Average Monthly Nitrogen Losses in Runoff (lb/ac)
Before Nutrient Management

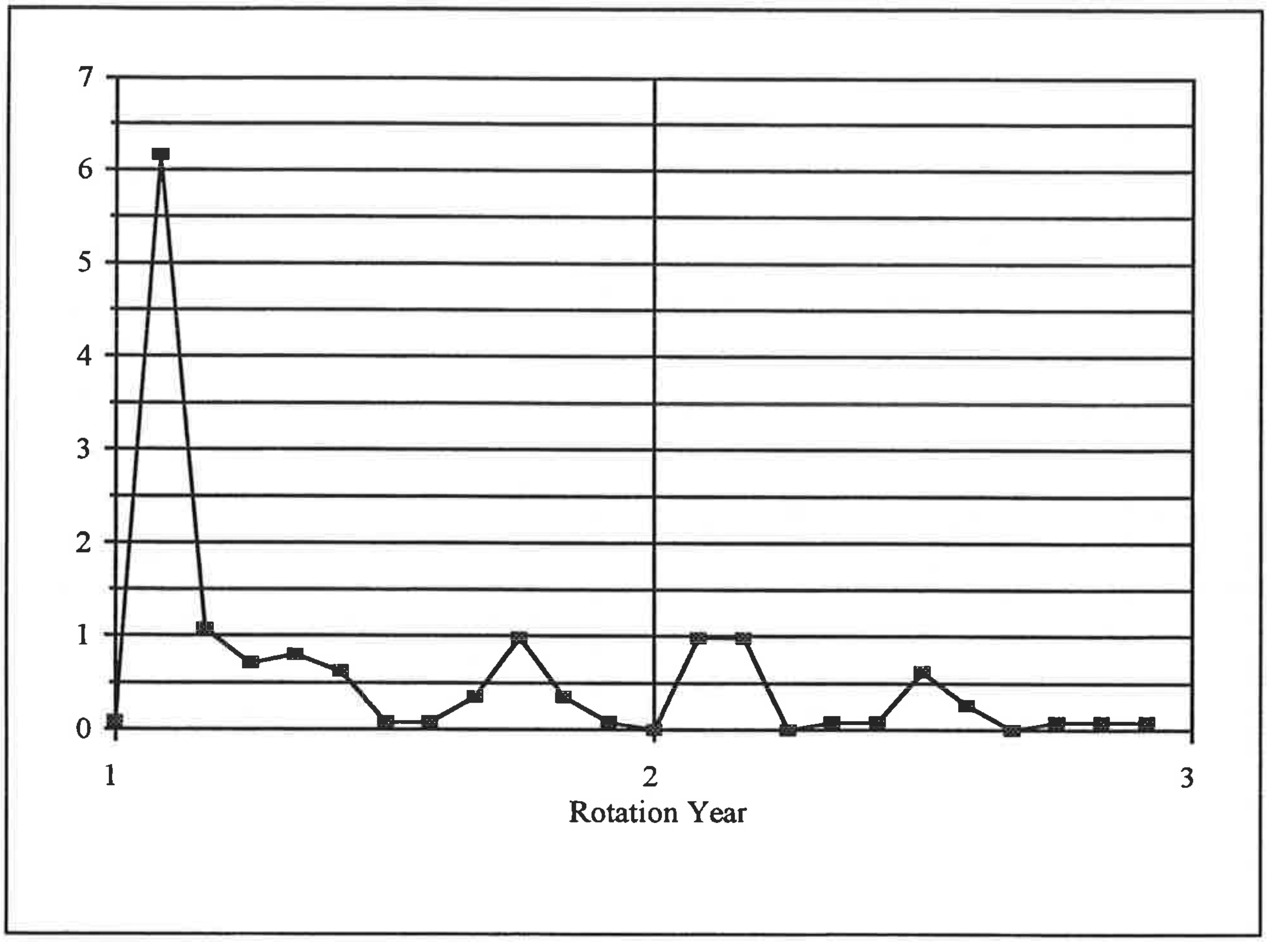

Figure 7.8
Poultry Operation in the Coastal Plain
Average Monthly Nitrogen Losses in Erosion (lb/ac)
Before Nutrient Management

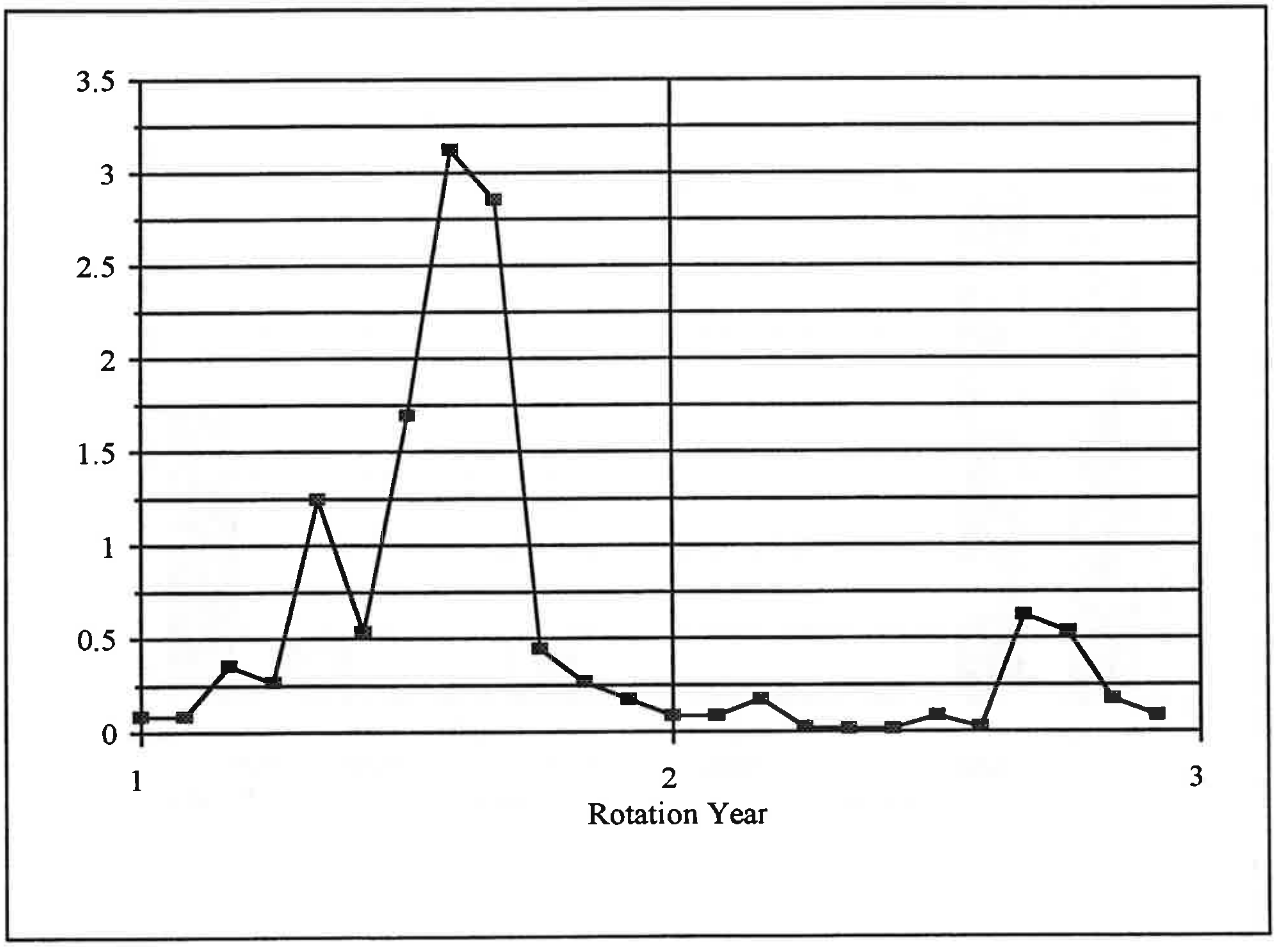

Figure 7.9
Poultry Operation in the Coastal Plain
Major Components of Average Annual Nitrogen Budget (in/ac)
After Nutrient Management

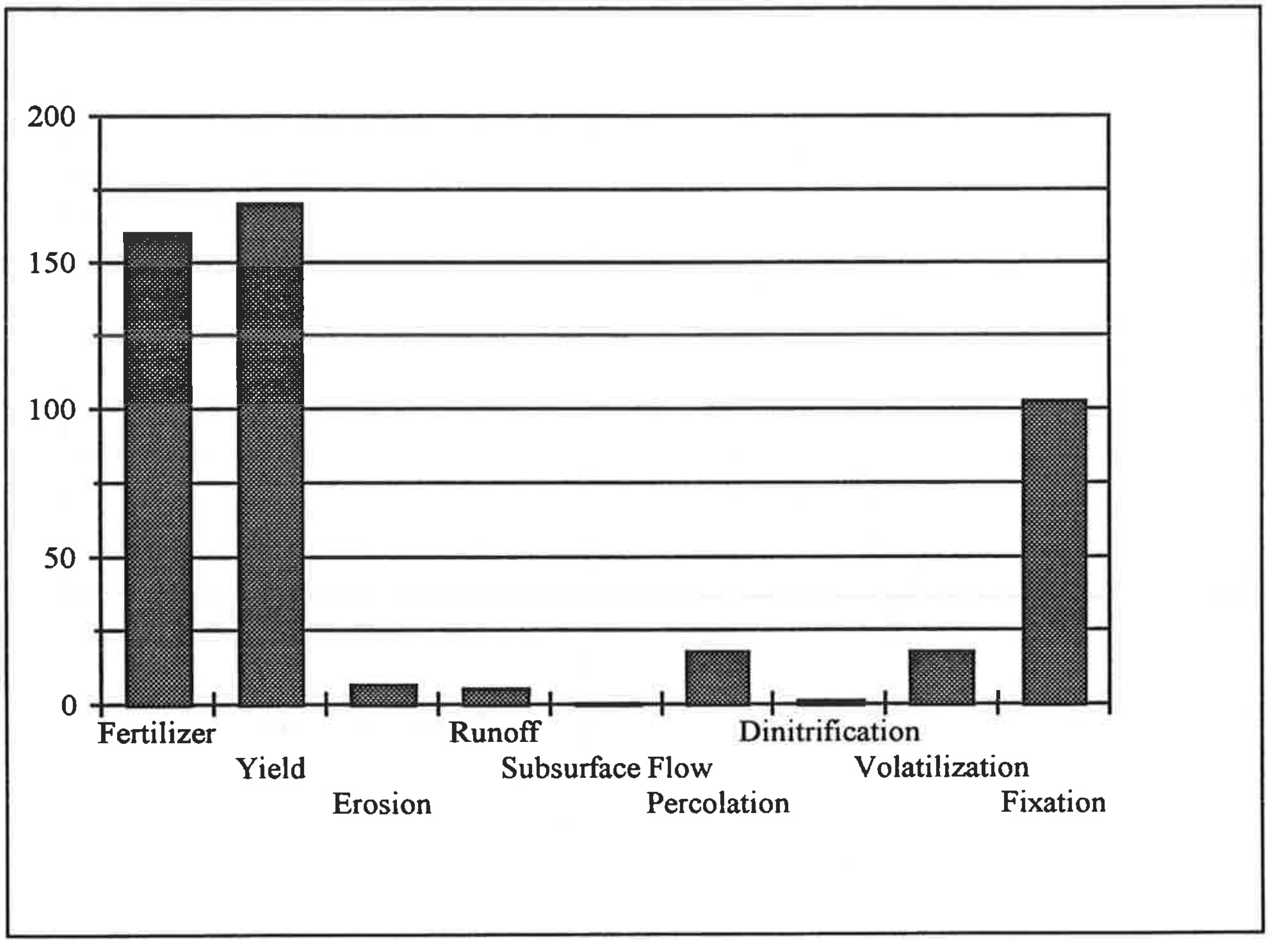

Figure 7.10
Poultry Operation in the Coastal Plain
Average Monthly Nitrogen Losses in Lateral Flow and Percolation (lb/ac)
After Nutrient Management

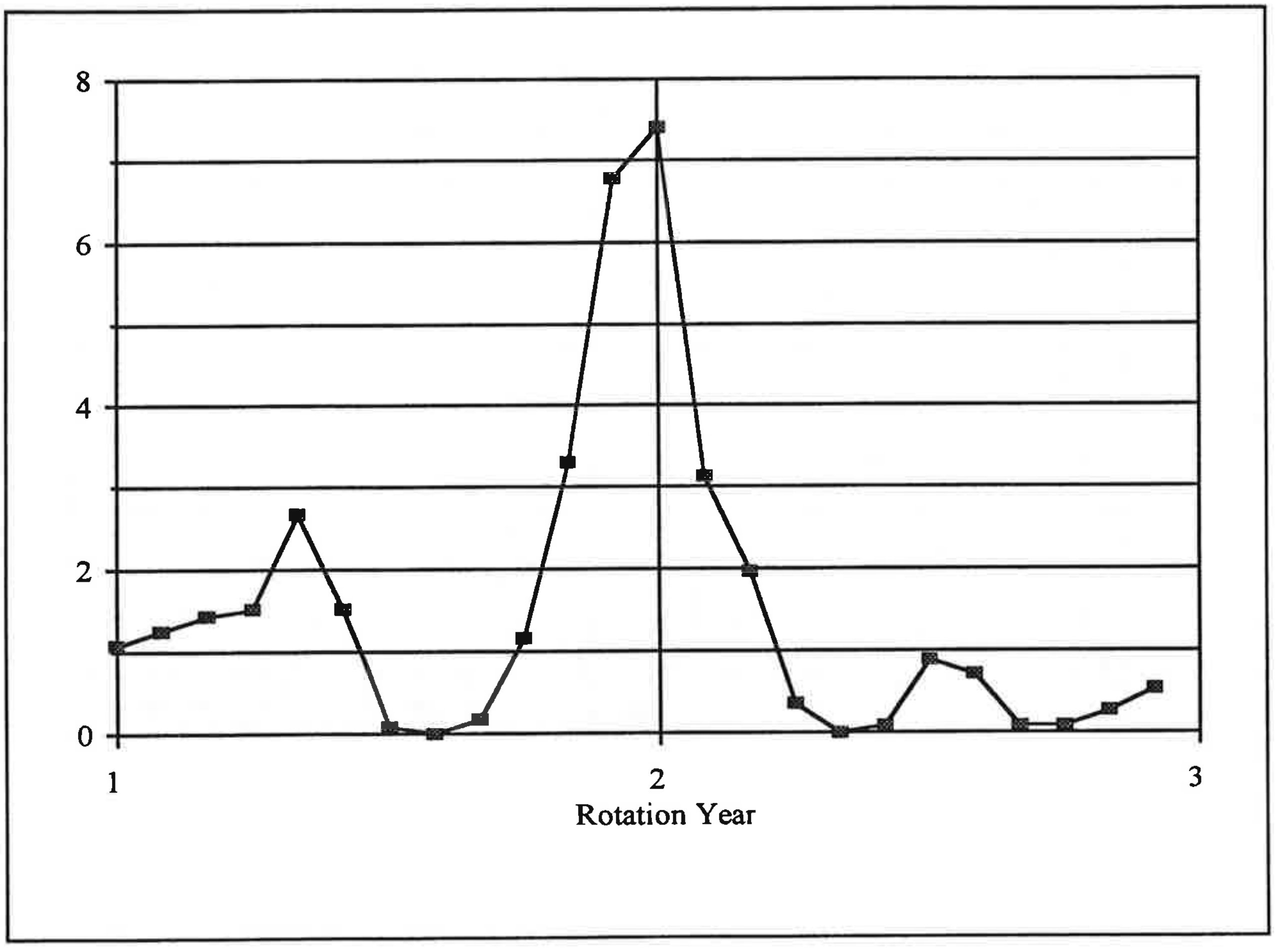

Figure 7.11
Poultry Operation in the Coastal Plain
Average Monthly Nitrogen Losses in Runoff (lb/ac)
After Nutrient Management

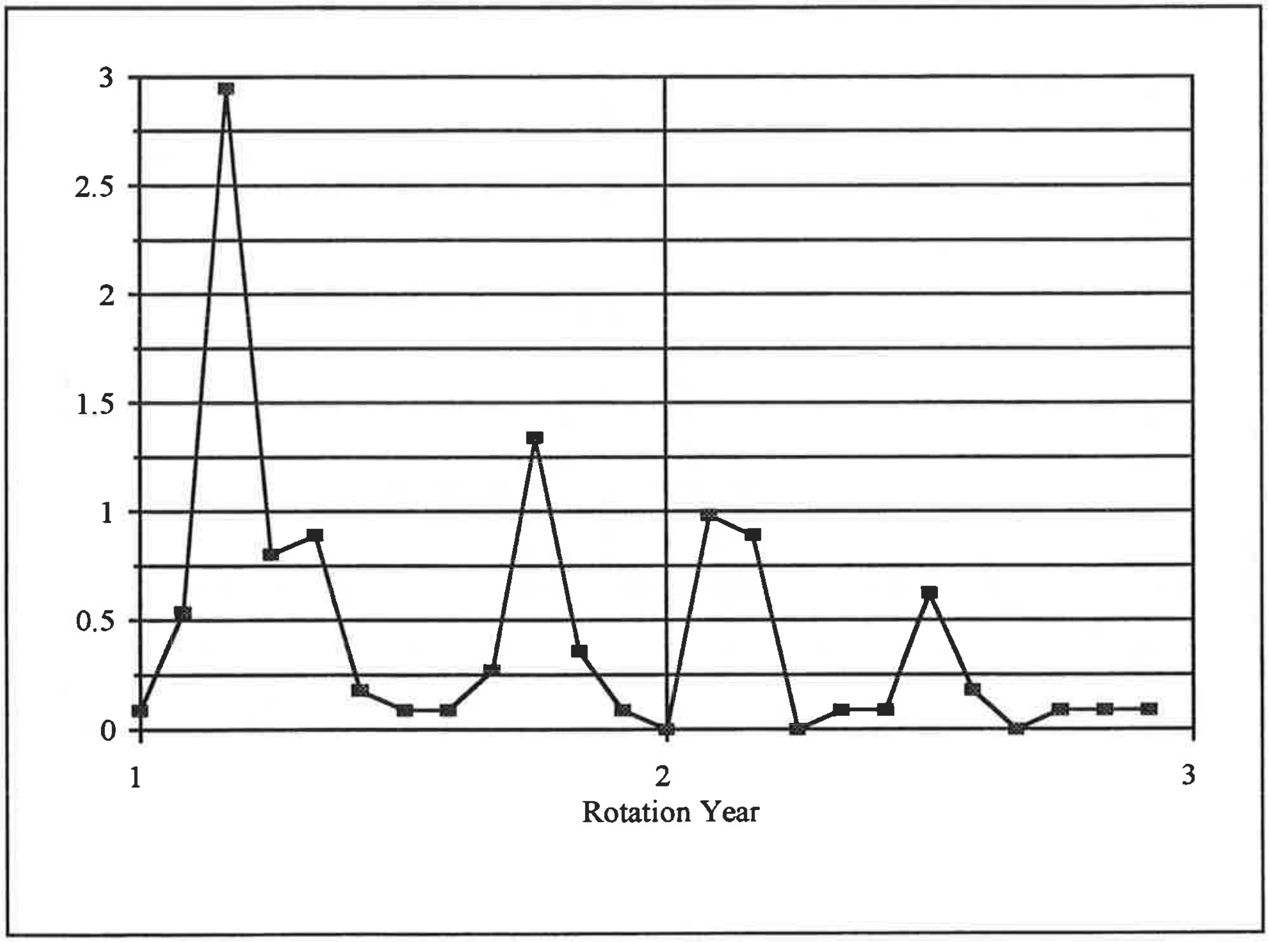

Figure 7.12
Poultry Operation in the Coastal Plain Average Annual Nitrogen Losses (lb/ac) As A Function of Poultry Litter Application Rate

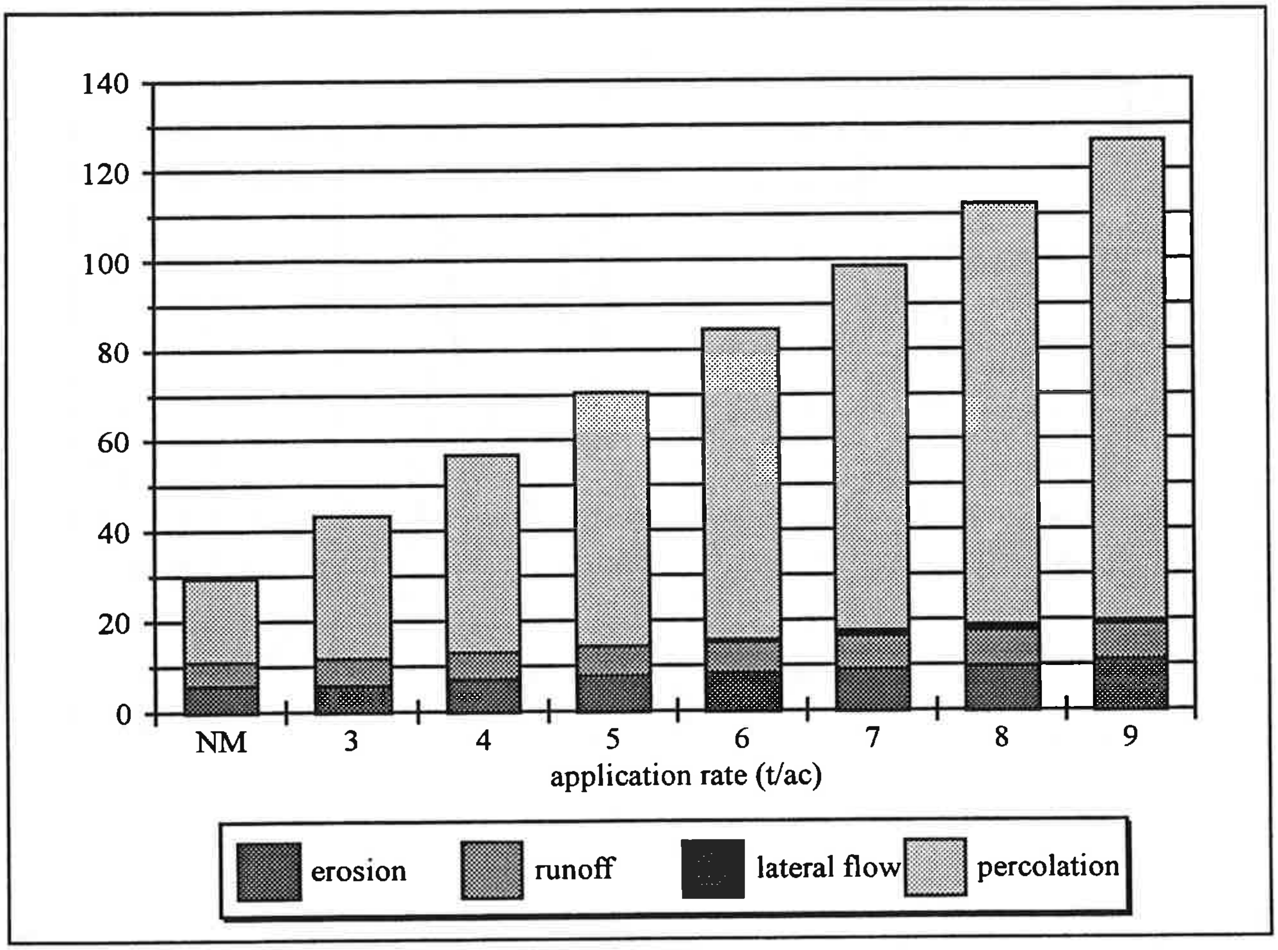

Figure 8.1
Cash Grain Operation in the Coastal Plain
Average Monthly Runoff (in/ac)
Inorganic Fertilizer

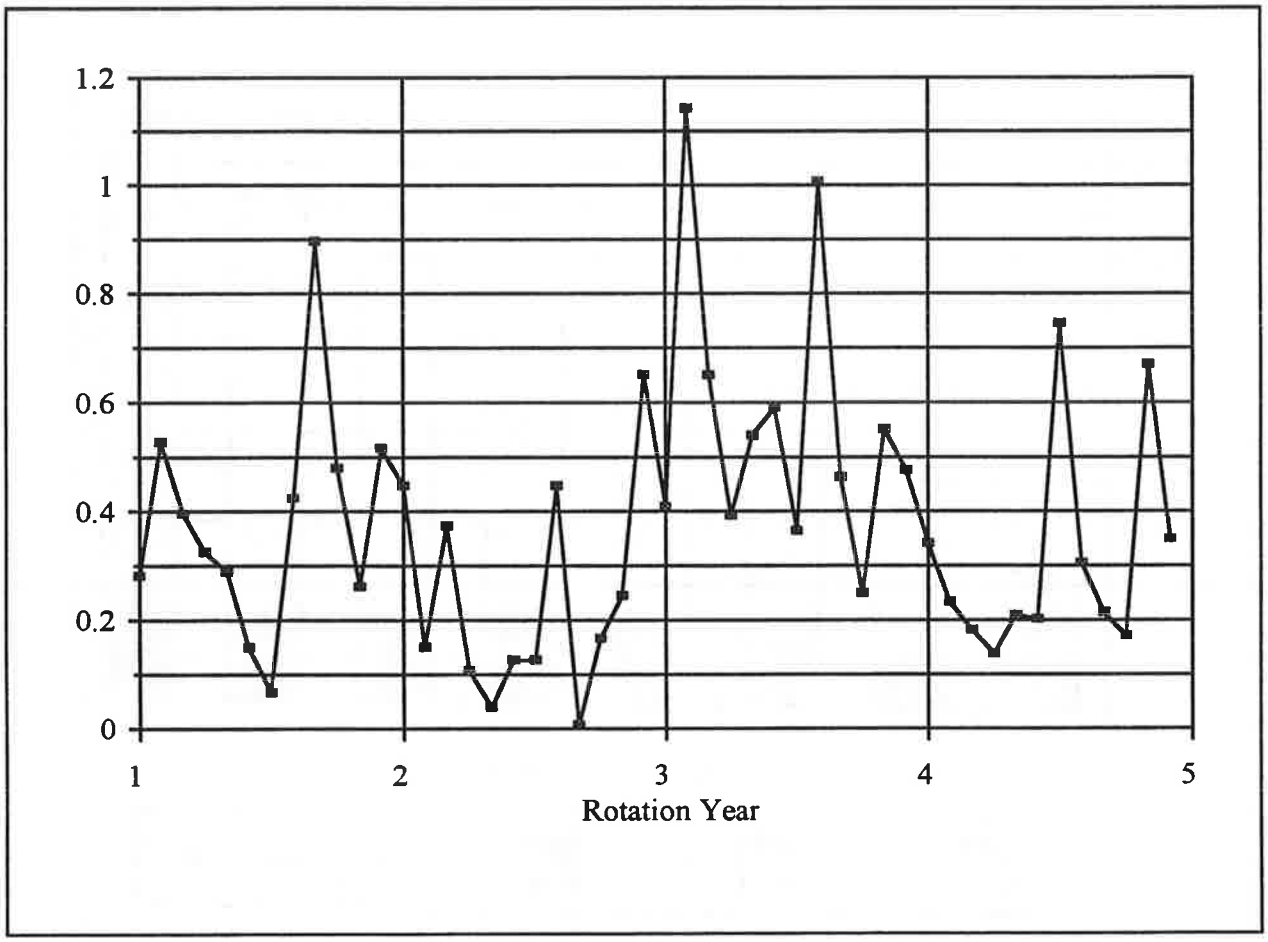

Figure 8.2
Cash Grain Operation in the Coastal Plain
Average Monthly Percolation (in/ac)
Inorganic Fertilizer

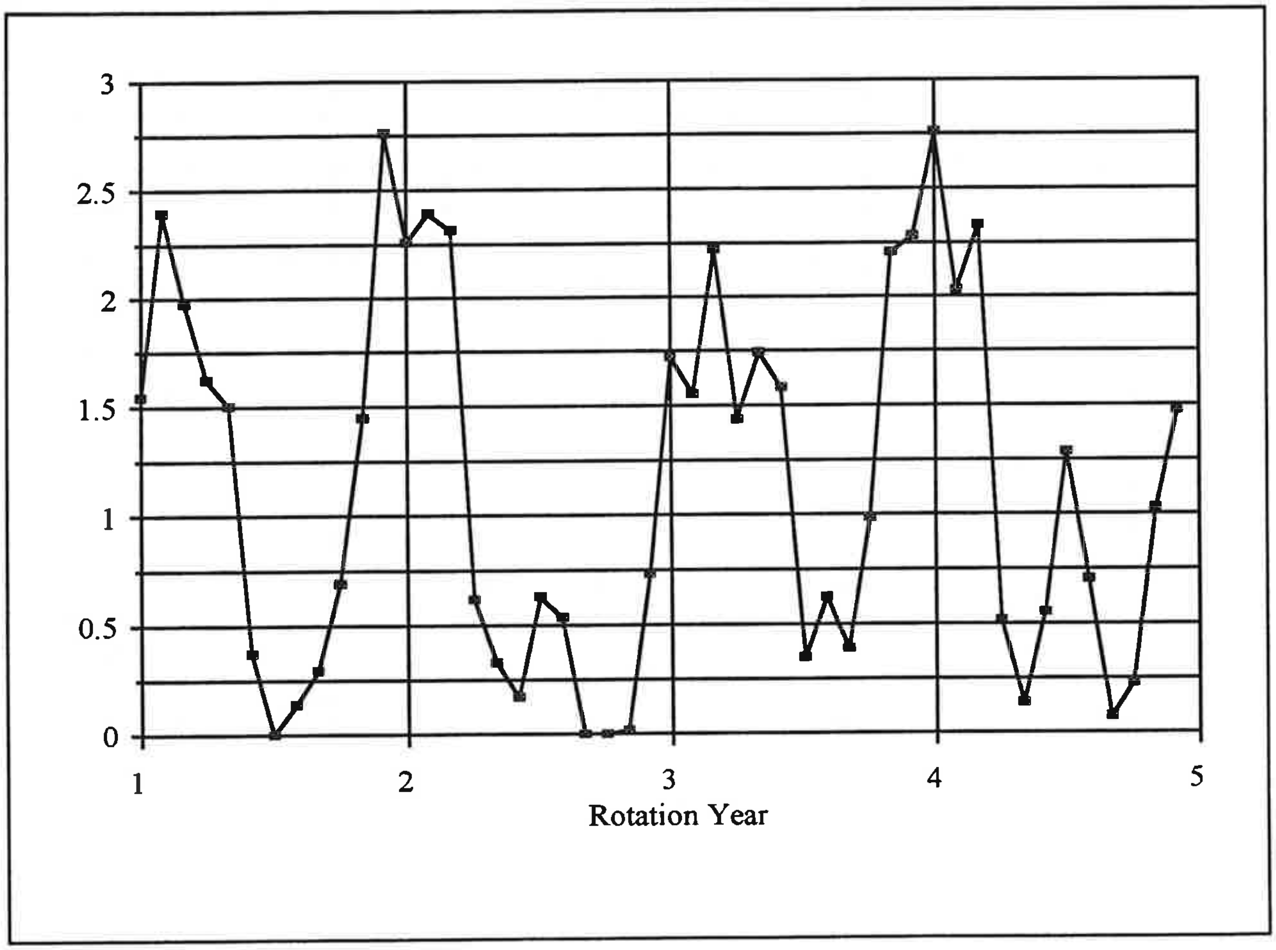

Figure 8.3
Cash Grain Operation in the Coastal Plain
Average Monthly Erosion (t/ac)
Inorganic Fertilizer

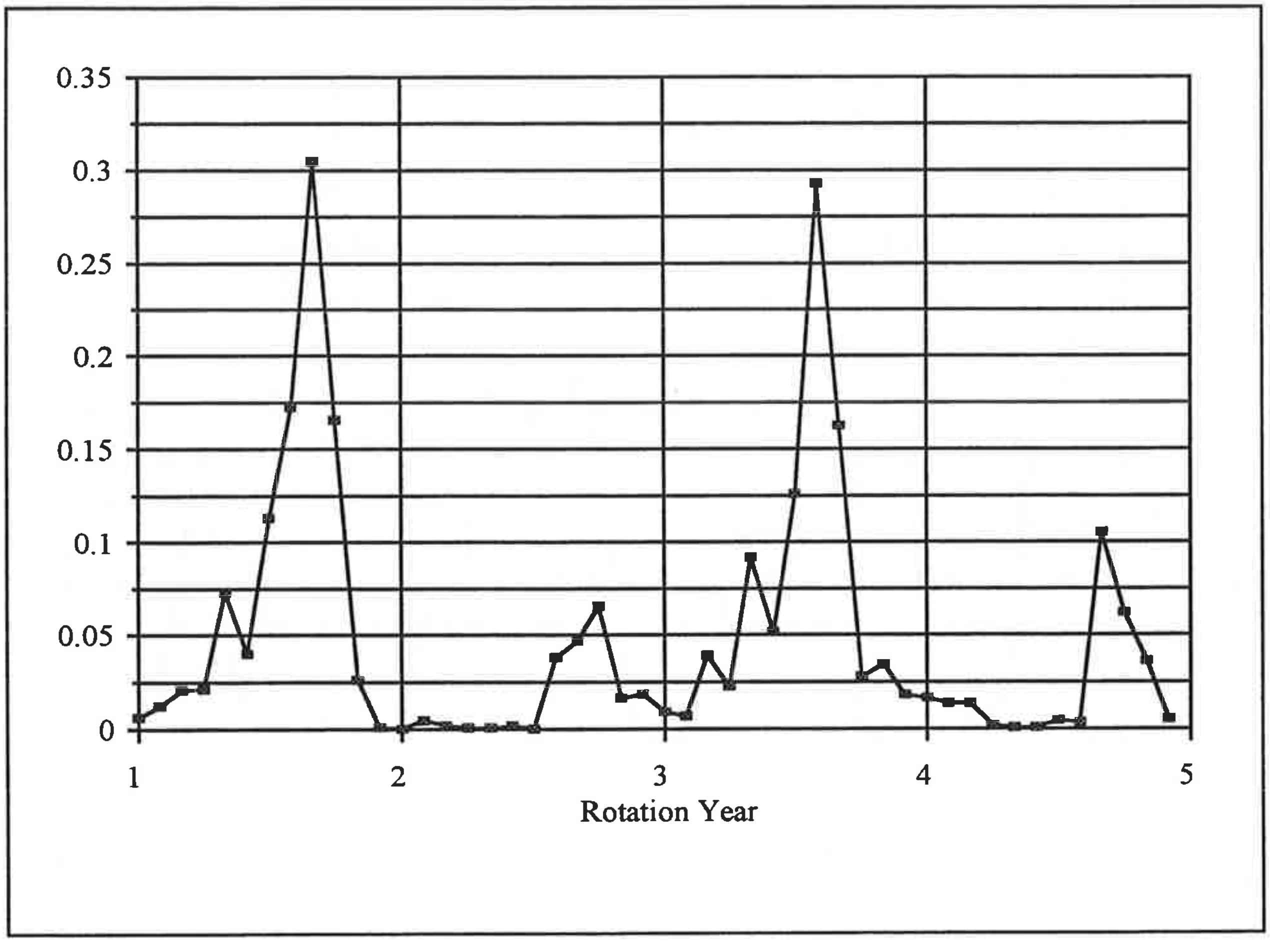

Figure 8.4
Cash Grain Operation in the Coastal Plain
Major Components of Average Annual Nitrogen Budget (lb/ac)
Inorganic Fertilizer

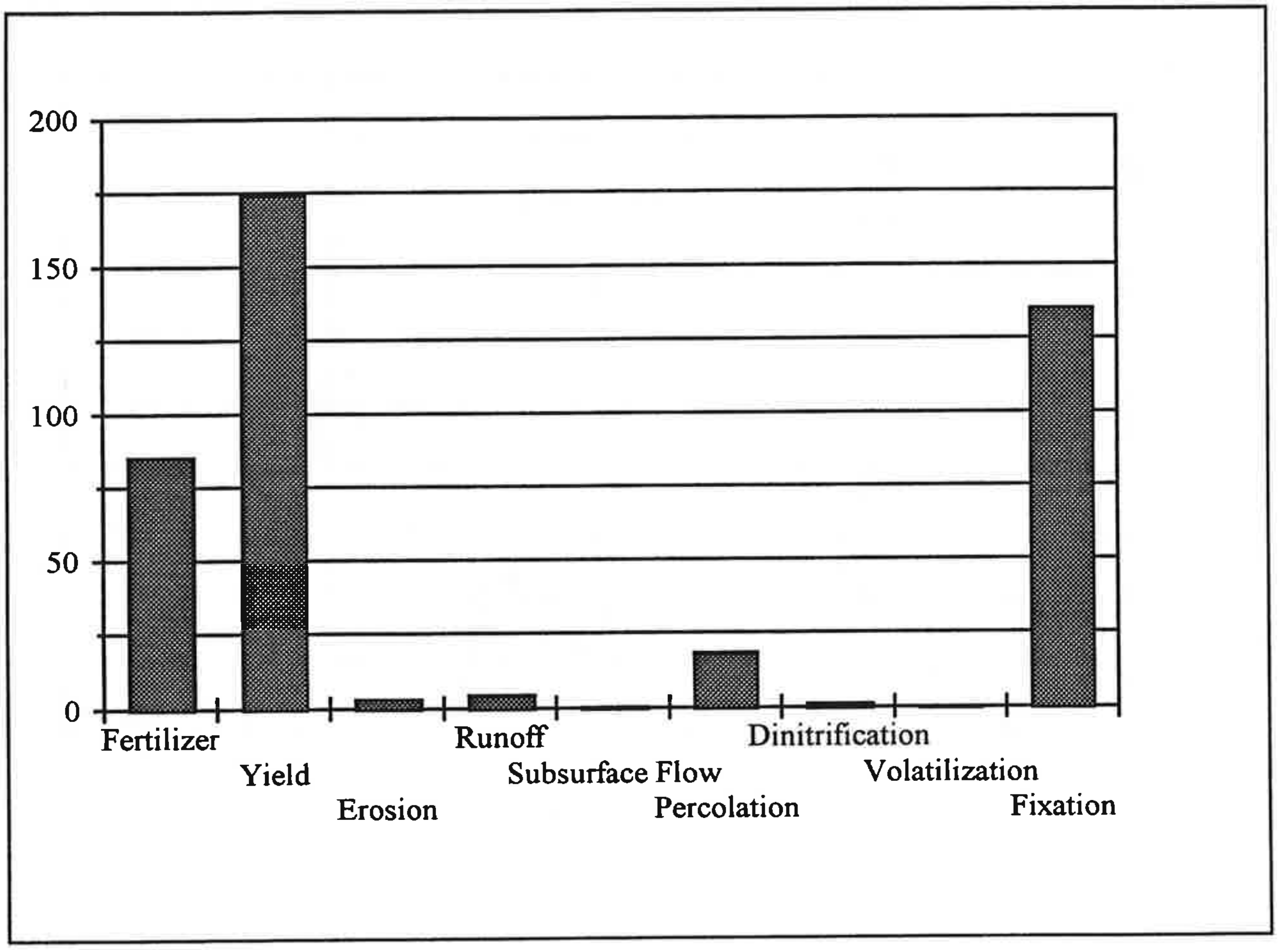

Figure 8.5
Cash Grain Operation in the Coastal Plain
Average Monthly Nitrogen Losses in Lateral Flow and Percolation (lb/ac)
Inorganic Fertilizer

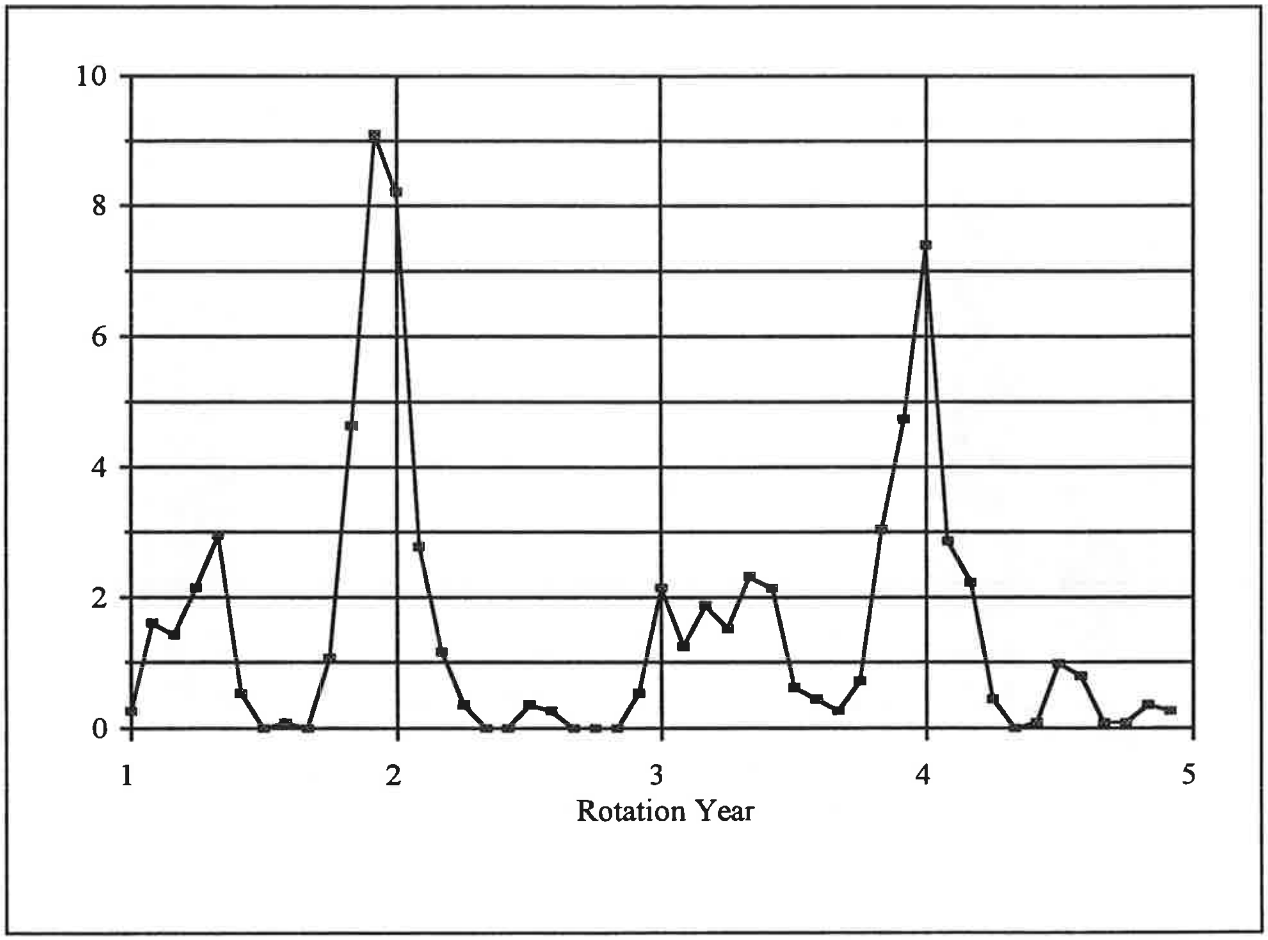

Figure 8.6
Cash Grain Operation in the Coastal Plain
Average Monthly Nitrogen Losses in Runoff (lb/ac)
Inorganic Fertilizer

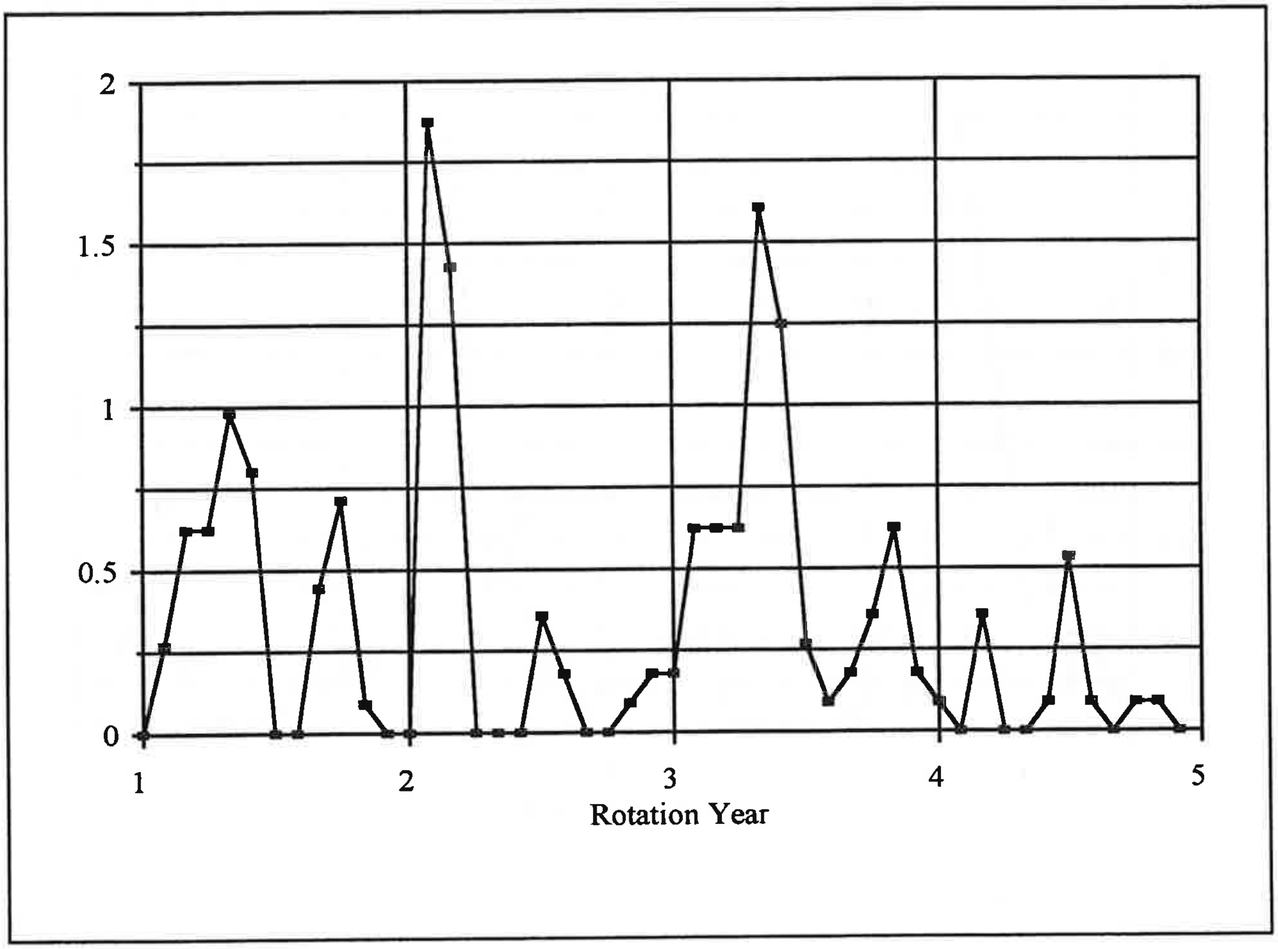

Figure 8.7
Cash Grain Operation in the Coastal Plain
Average Monthly Nitrogen Losses in Erosion (lb/ac)
Inorganic Fertilizer

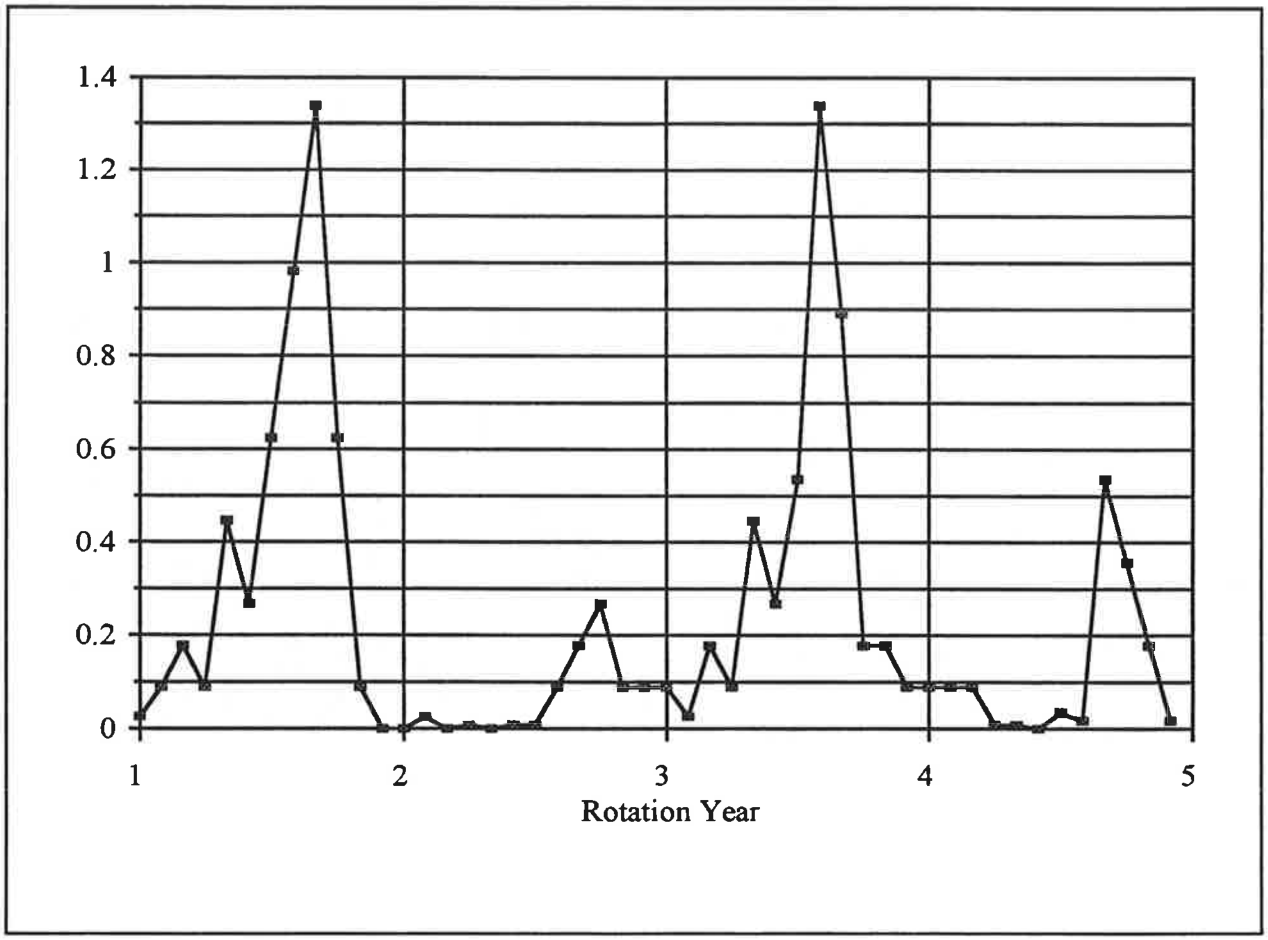

Figure 9.1
Poultry and Cash Grain Operation in the Costal Plain
Average Monthly Percolation (in/ac)
Before Nutrient Management

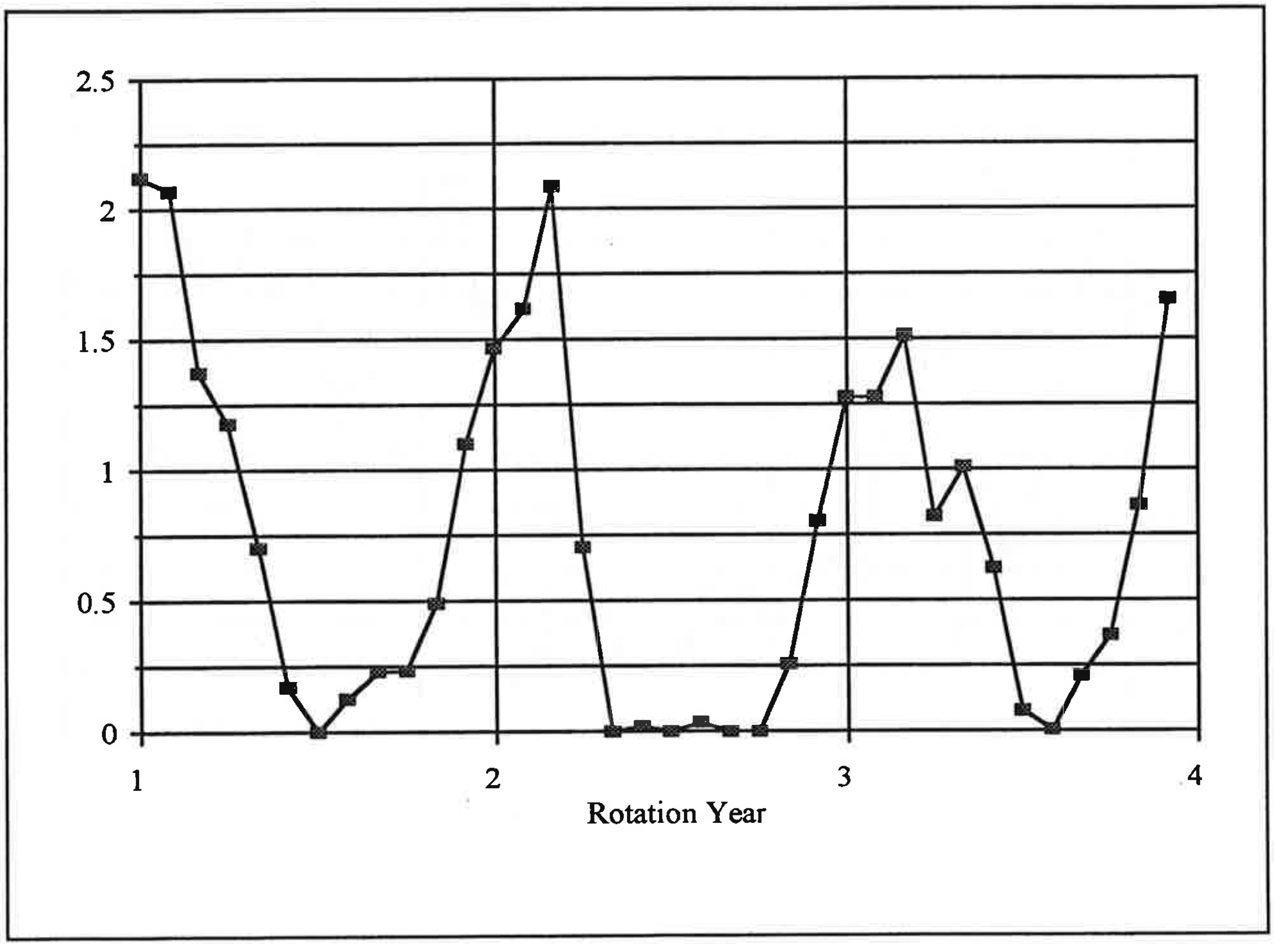

Figure 9.2
Poultry and Cash Grain Operation in the Costal Plain
Average Annual Monthly Runoff (in/ac)
Before Nutrient Management

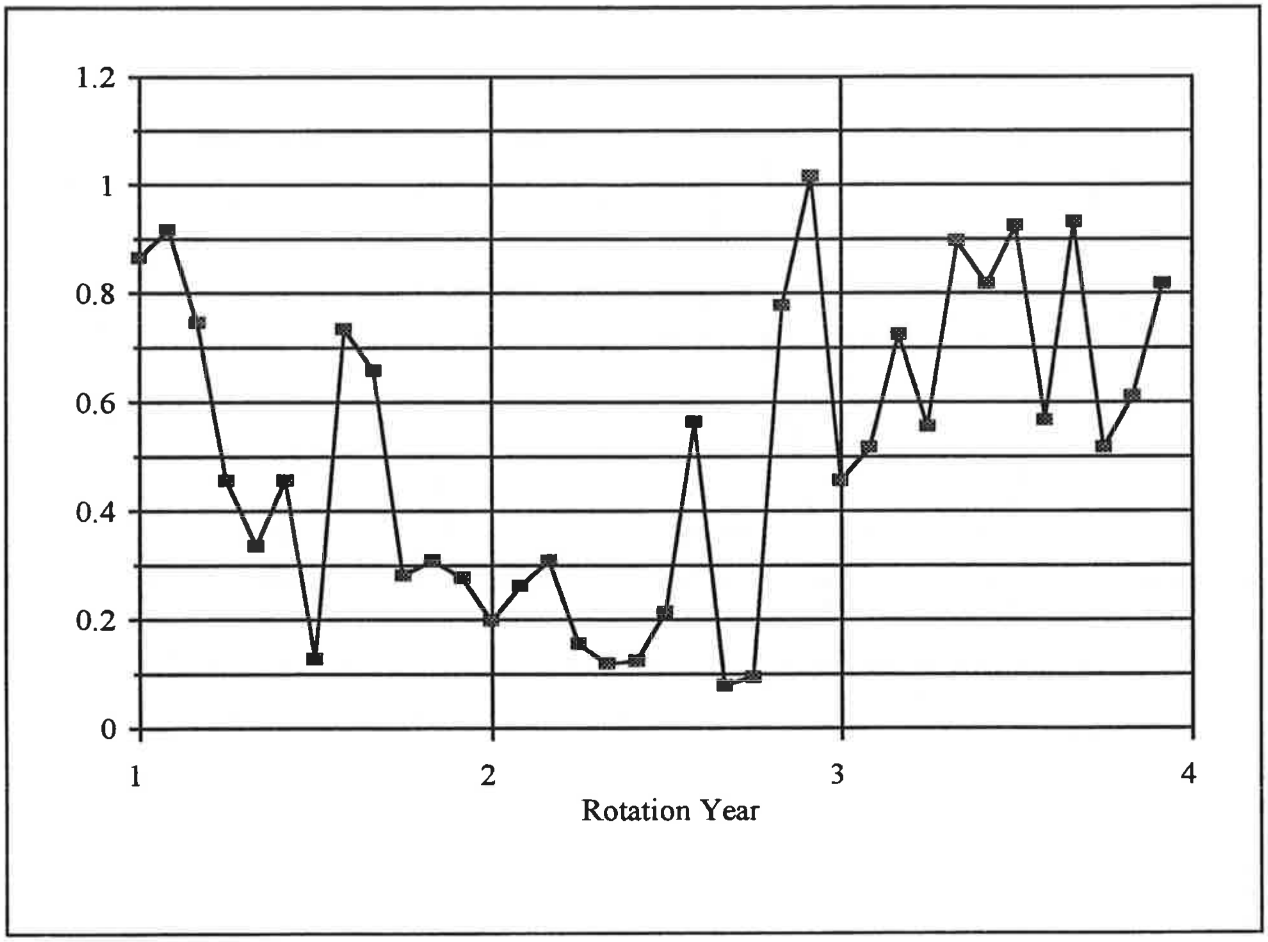

Figure 9.3
Poultry and Cash Grain Operation in the Costal Plain
Average Monthly Erosion (t/ac)
Before Nutrient Management

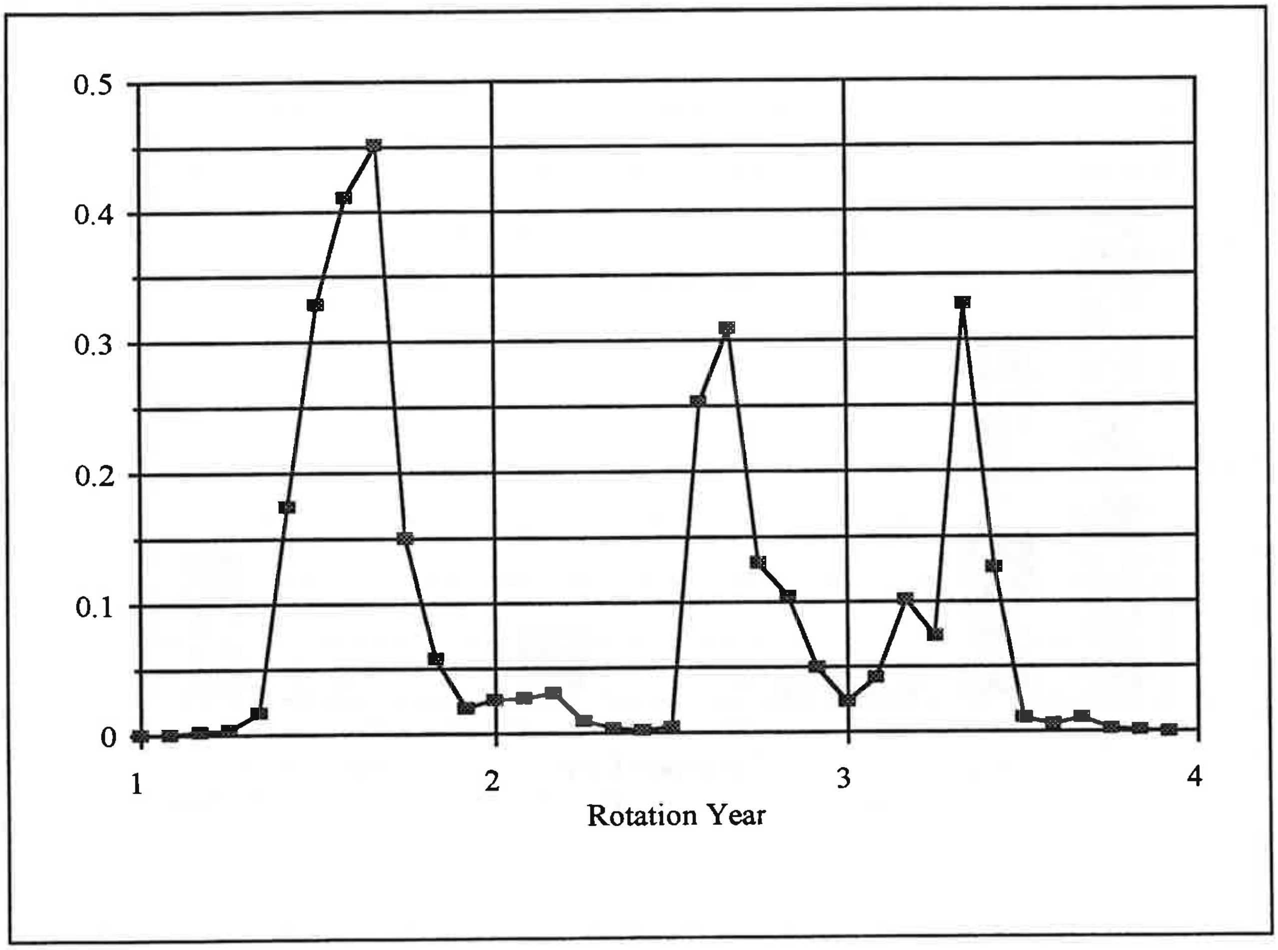

Figure 9.4
Poultry and Cash Grain Operation in the Costal Plain
Major Components of Average Annual Nitrogen Budget (lb/ac)
Before Nutrient Management

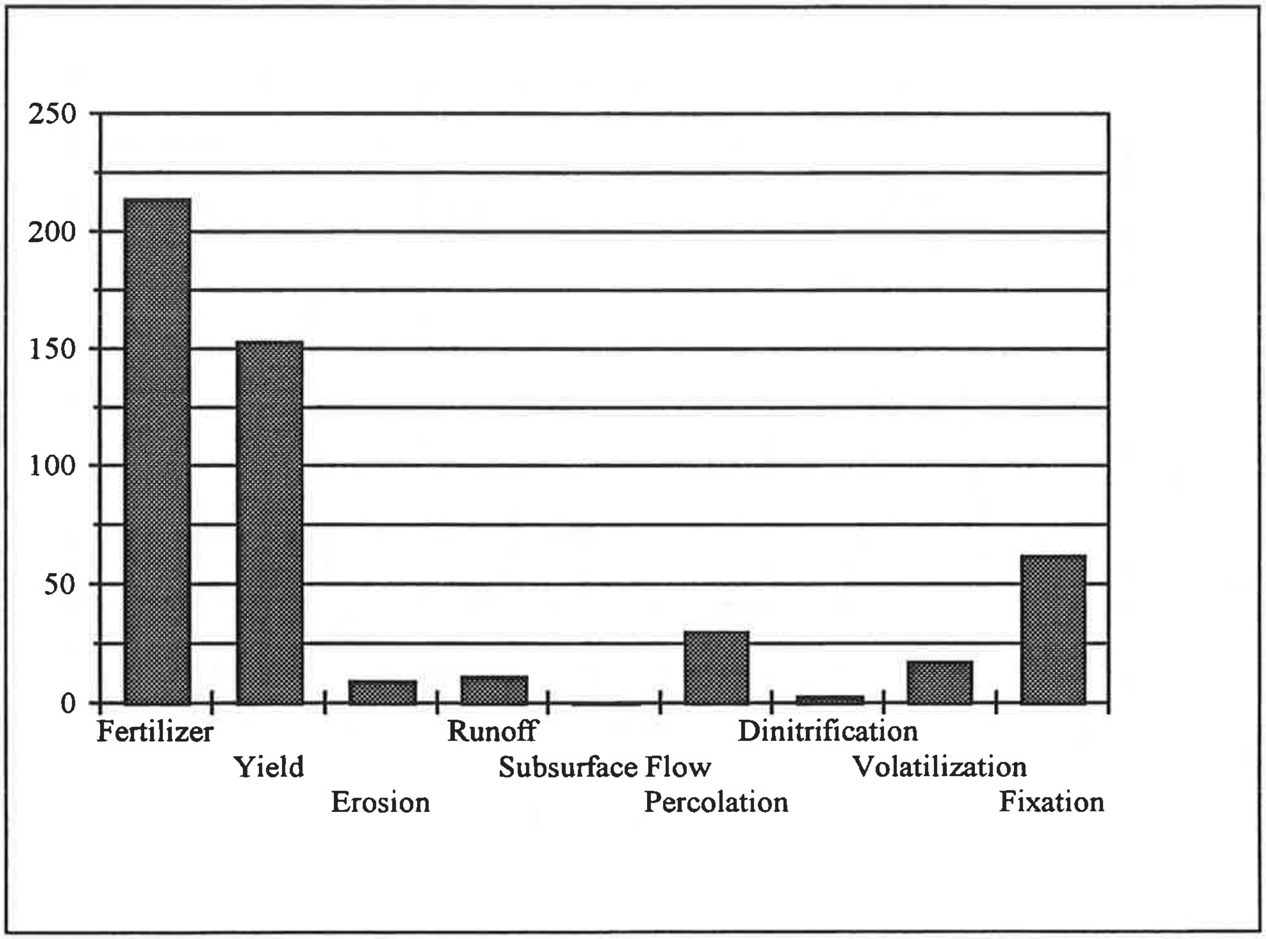

Figure 9.5
Poultry and Cash Grain Operation in the Costal Plain Average Monthly Nitrogen Losses in Lateral Flow and Percolation (lb/ac) Before Nutrient Management

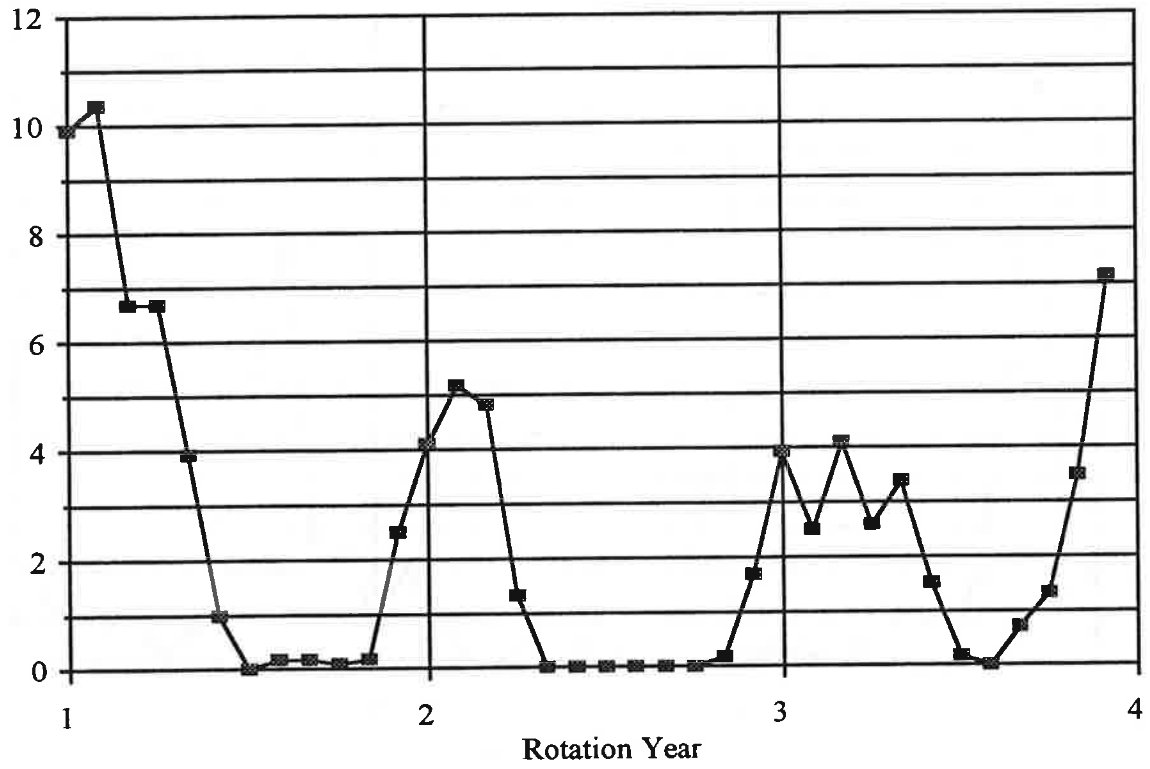

Figure 9.6
Poultry and Cash Grain Operation in the Costal Plain
Average Monthly Nitrogen Losses in Runoff (lb/ac)
Before Nutrient Management

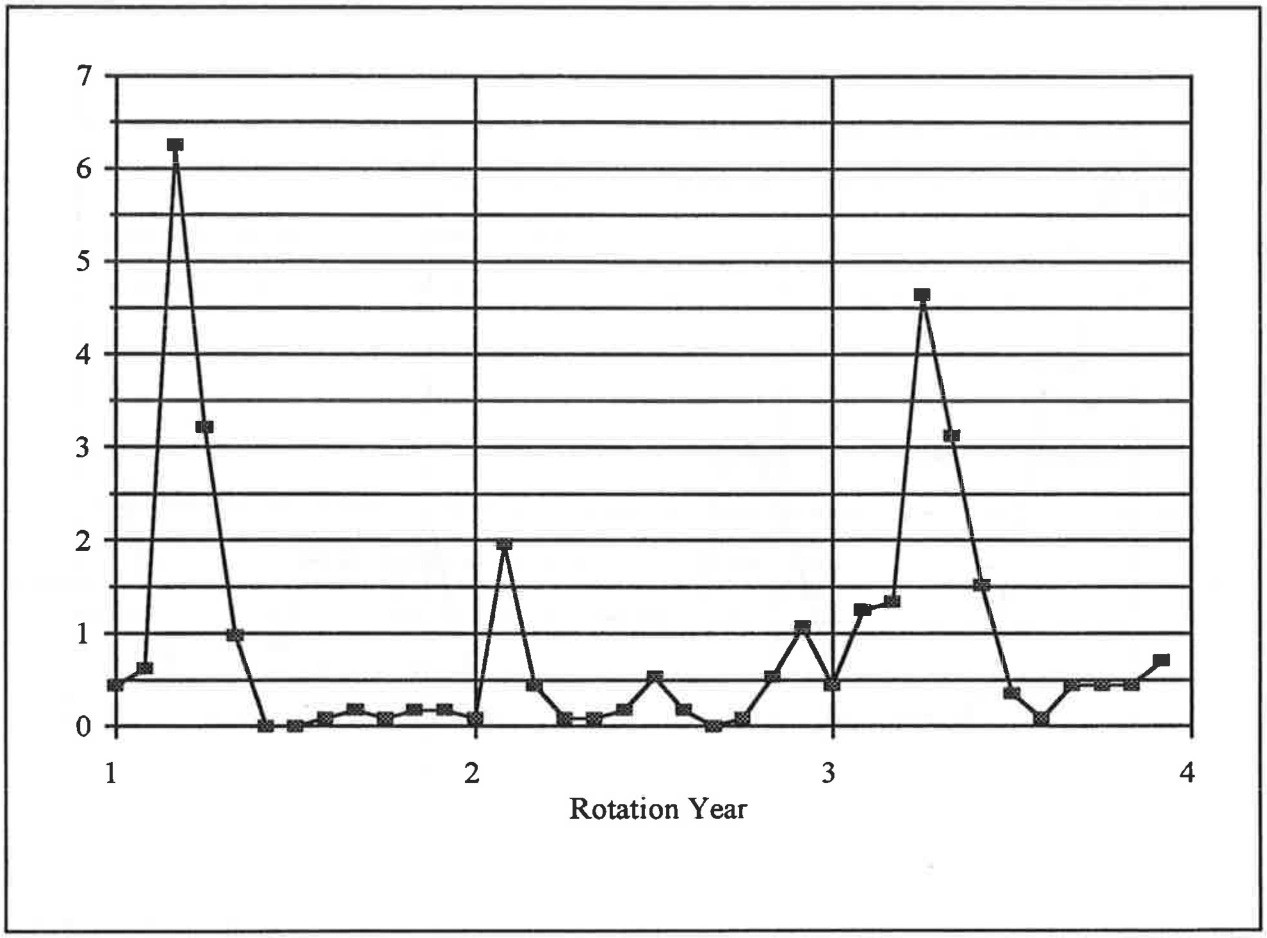

Figure 9.7
Poultry and Cash Grain Operation in the Costal Plain
Average Monthly Nitrogen Losses in Erosion (lb/ac)
Before Nutrient Management

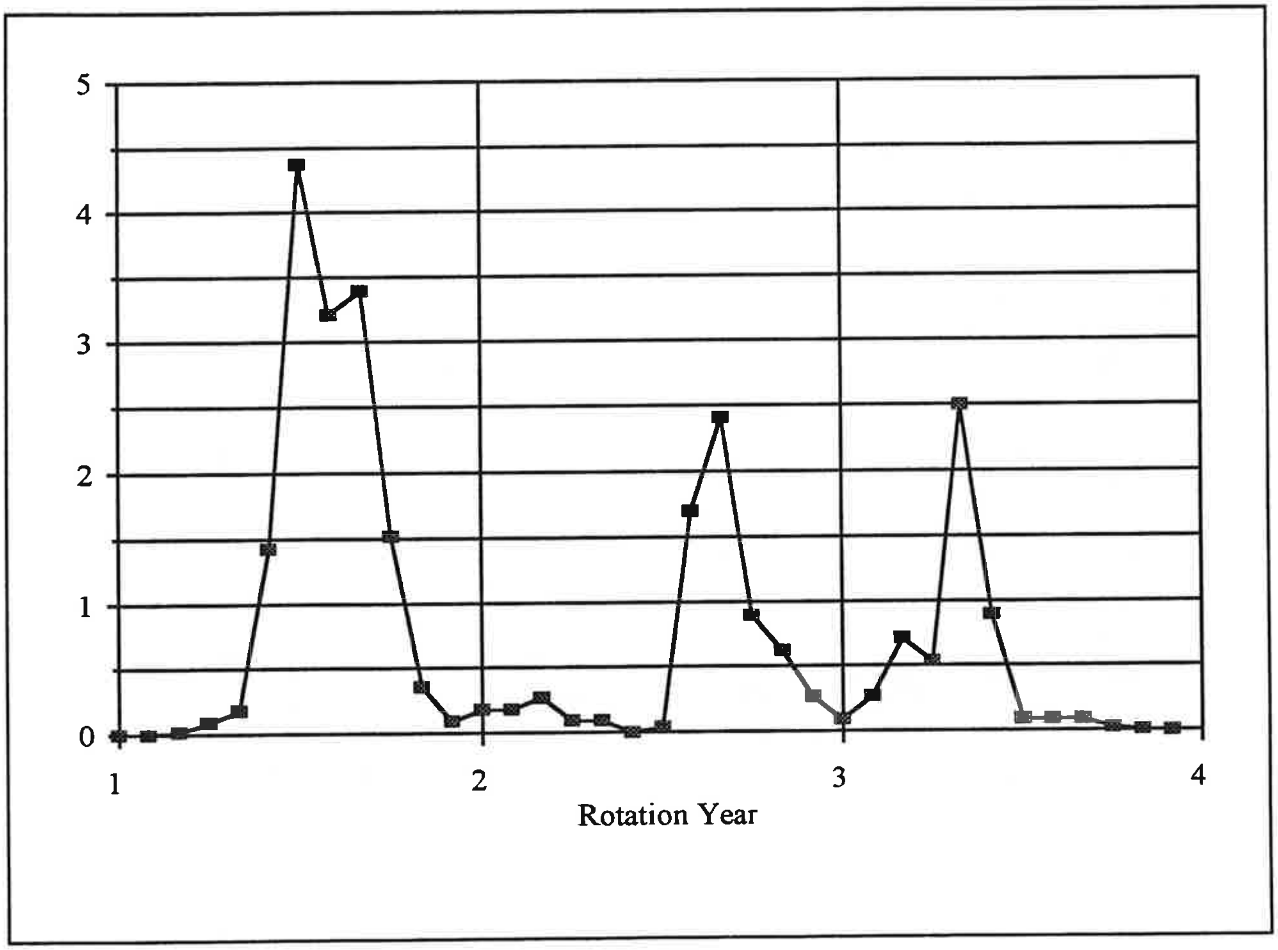

Figure 9.8
Poultry and Cash Grain Operation in the Costal Plain
Major Components of Average Annual Nitrogen Budget (lb/ac)
After Nutrient Management

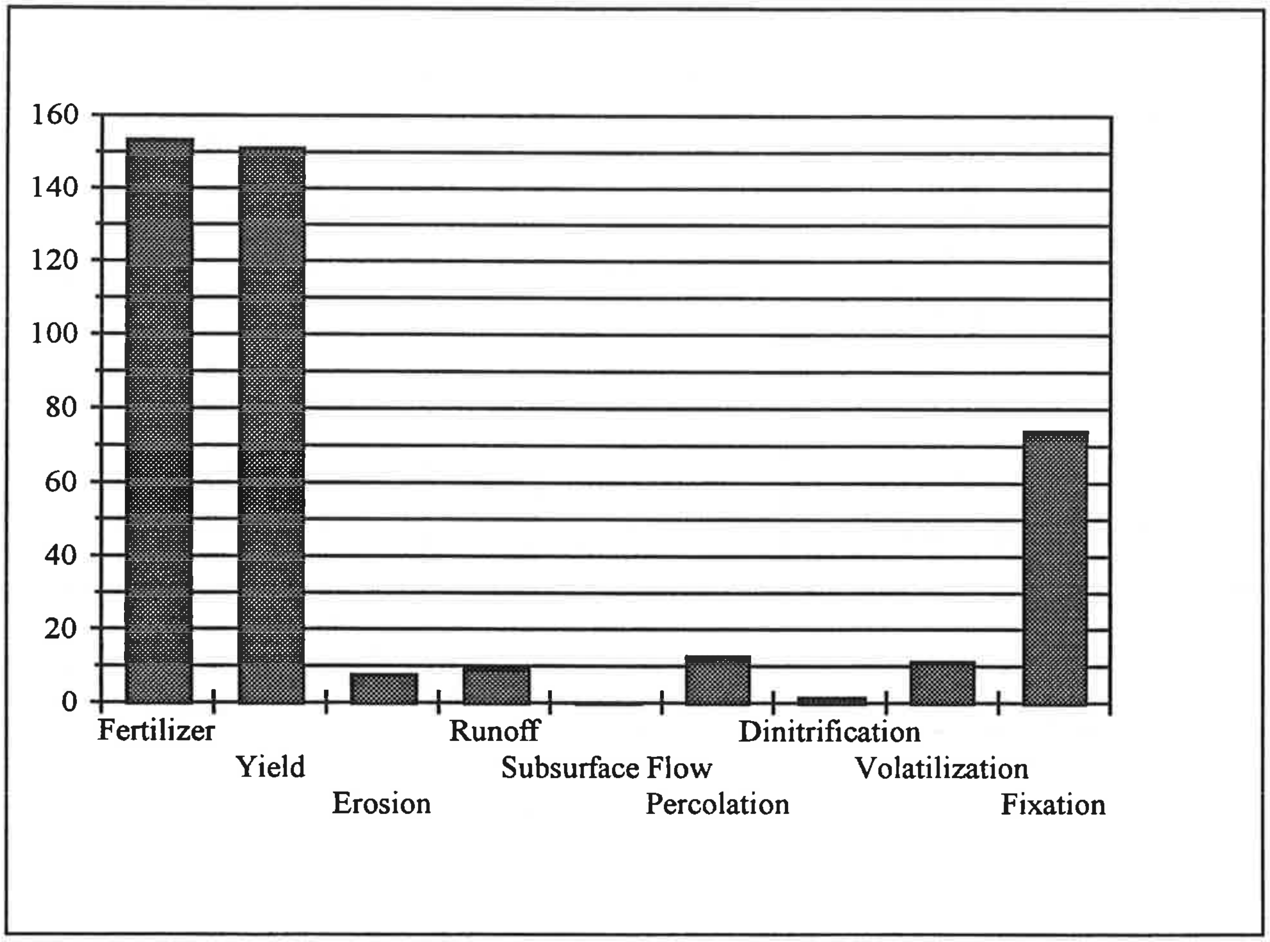

Figure 9.9
Poultry and Cash Grain Operation in the Costal Plain
Average Monthly Nitrogen Losses in Lateral Flow and Percolation (lb/ac)
After Nutrient Management

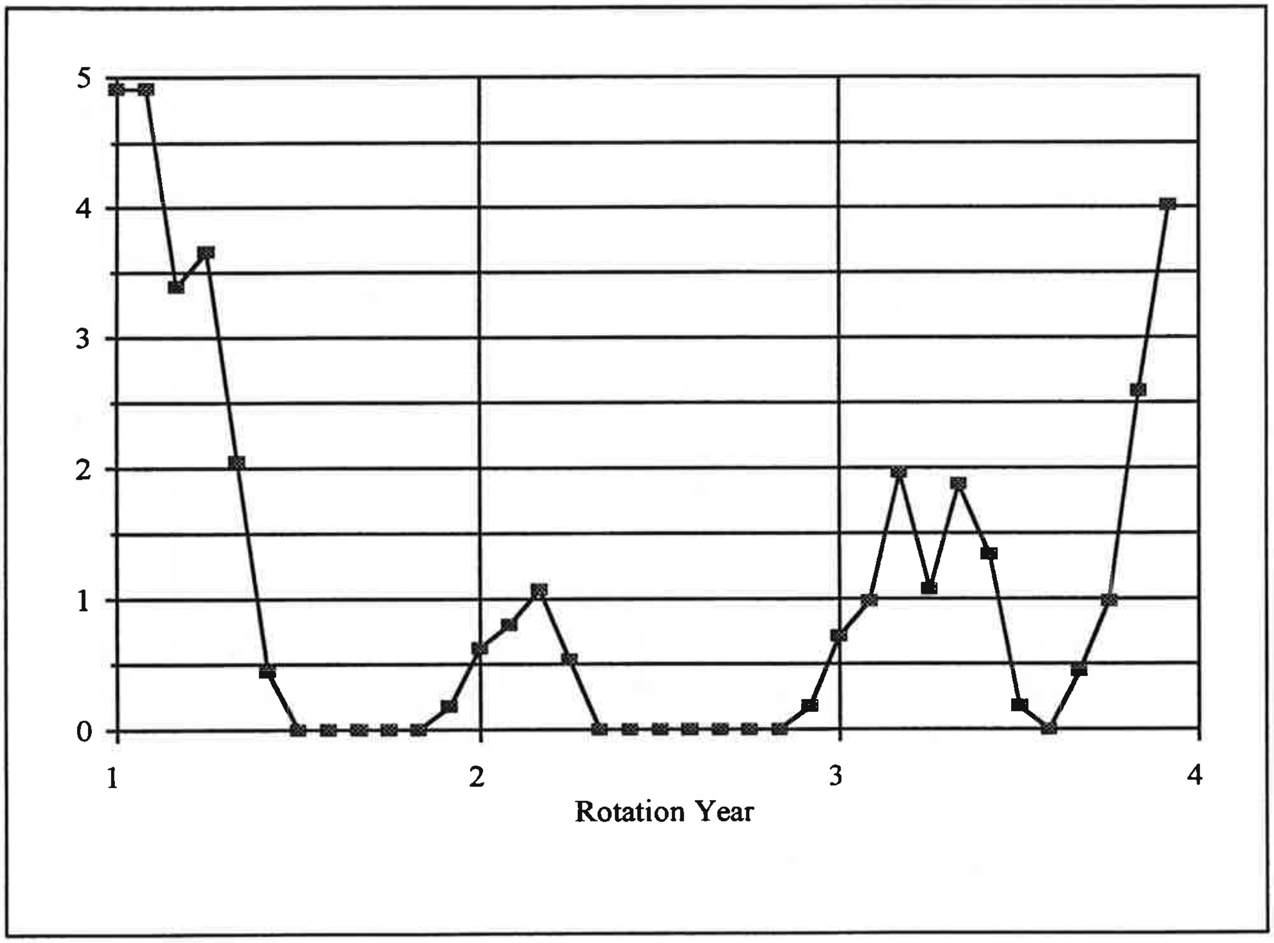

Table 9.10
Poultry and Cash Grain Operation in the Coastal Plain
Average Annual Nitrogen Losses
As Function of Poultry Manure Application Rate