SIMULATED EFFECTS OF AGRICULTURAL MANAGEMENT SYSTEMS ON POTENTIAL NONPOINT SOURCE LOADING OF NITRATE AND PESTICIDES

by

Peter Edward Davis

Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
Master of Science
in
Agricultural Engineering

APPROVED:

Conrad D. Heatwole
C. D. Heatwole, Chairman

Theo A Dillaha III
T. A. Dillaha III

S. Mostaghimi

Daniel L Gallagher
D. L. Gallagher

J. V. Perumpral

May, 1991

Blacksburg, Virginia

SIMULATED EFFECTS OF AGRICULTURAL MANAGEMENT SYSTEMS ON POTENTIAL NONPOINT SOURCE LOADING OF NITRATE AND PESTICIDES

by

Peter Edward Davis

Conrad D. Heatwole, Chairman

Agricultural Engineering

(ABSTRACT)

Long-term CREAMS and GLEAMS model simulations were used to assess significant differences in potential pesticide and nitrate movement to groundwater as affected by several combinations of tillage, cropping, and nutrient and pesticide management practices. The study area is in Richmond County in the Coastal Plain region of Virginia. Alternative management scenarios were based on crop management systems common to the area. Average annual loads from 35-year simulations were used in the analysis. Friedman's distribution-free analysis of variance and sign tests were found to be appropriate statistical procedures to assess significant differences between effects of management practices.

Commercial nitrogen split-applied at recommended rates leached less than equivalently applied N from a single pre-plant poultry litter application. Leaching increased, but differences were less, when split-applied commercial N and pre-plant poultry litter applications were increased, with both sources apparently supplying N in excess of crop uptake potential. A 3-way instead of a 2-way split commercial N application reduced nitrate leaching minimally. Though tillage-cropping practices did affect percolation volumes, this did not result in high variability in leaching between practices. Leaching was most sensitive to crop-available N inputs regardless of tillage-cropping practices or the methods of N application.

Pesticides with lower soil-adsorptivity, such as atrazine, had greater leaching losses especially on rotations with higher infiltration. However, a relatively high surface-

application rate of atrazine for no-till corn did not produce higher leaching losses because additional losses were mostly by volatilization. Surface losses of highly adsorbed chemicals, such as gramoxone, were substantially reduced from no-till fields where runoff and erosion were reduced. Percent reductions in pesticide application rates resulted in equal or greater percent reductions in loading in surface runoff and percolation.

ACKNOWLEDGEMENTS

I would like to thank each member of my examining committee, Dr. Conrad D. Heatwole, Dr. Saied Mostaghimi, Dr. Theo A. Dillaha, Dr. Daniel L. Gallagher, and Dr. John V. Perumpral. Their friendly attitude and assistance helped make my time at Virginia Tech pleasant and rewarding. Their teaching was instrumental to my understanding of NPS modeling concepts which I applied to the development of this thesis.

I especially appreciate Dr. Heatwole's efficiency in providing me useful work at assisting Penny Diebel with data acquisition from CREAMS and GLEAMS simulations. This work became an appropriate basis for my thesis. Dr. Heatwole's modification of the CREAMS model enabled summarized output which was easier to work with, and also provided a more useful means of simulating organic nitrogen input. Dr. Heatwole also deserves a great deal of thanks for his invaluable editorial contributions which greatly improved the final presentation of my work.

I would also like to thank Penny Diebel for providing detailed information about existing and potential alternative agricultural practices in Richmond County, Virginia. I was pleased that a thesis topic developed from our work together, and that the simulated water quality impacts of those agricultural practices were useful for economic evaluation in Penny's dissertation.

I would like to thank Dr. Robert Foutz for his consultations with me regarding the statistical techniques that I pursued to compare simulated effects of agricultural management practices on water quality.

Many thanks to all the graduate students for friendship and assistance during my time in Blacksburg.

Finally, I wish to acknowledge the financial support provided by the department of Agricultural Engineering, Virginia Polytechnic Institute and State University, and funding of LISA research by the Environmental Protection Agency and the U.S. Geological Survey.

TABLE OF CONTENTS

INTRODUCTION

BACKGROUND

Efforts to control nonpoint source (NPS) pollution include Federal policies designed to encourage agricultural practices that are environmentally sound and economically viable. However, conclusions regarding the overall effectiveness and recommended implementation of best management practices (BMPs) to reduce NPS pollution are often misleading generalizations extrapolated from limited data. BMPs must be evaluated on a site-specific basis within a particular region, such as the Chesapeake Bay drainage basin, so that particular agricultural practices, economics, and environmental concerns for the region are addressed.

Experimental research on NPS pollution from agricultural management activities often involves comparing effects of a single component of management to a conventional standard, for example, the effect of no-till versus conventional tillage on erosion. However, to realize the holistic benefit to the farm economy and environment, integral management components such as tillage, cropping, and nutrient and pesticide management practices should be evaluated in realistic combinations until the most suitable combination of BMPs can be identified.

Management practices that have been proven to reduce erosion, runoff, and in many cases, soluble and adsorbed agrichemical delivery to surface waters need further evaluation for their potentially adverse impacts on groundwater. Development of specific nutrient and pesticide management practices for use with crop rotations and conservation tillage practices is necessary in the Chesapeake Bay drainage basin where the protection of ground and surface water resources has been mandated. In the Virginia Coastal Plain region adjacent to the bay, the sandy soils and low slopes are likely to result in higher percolation losses than surface losses of nitrate and most pesticides. BMPs shown to reduce erosion, runoff, and contaminant transport by runoff and sediment may not be effective from a groundwater quality standpoint unless pesticide and nutrient management practices are carefully integrated as a part of the overall agricultural management practice.

Comprehensive evaluation of BMPs requires a tremendous amount of data. Mathematical models have facilitated the evaluation of a wide range of practices, providing a relative comparison of the impacts on water quality. Models can provide an inexpensive means of extending observed data and increasing the information on which management and regulatory decisions are based. Nevertheless, model development and use relies on observed hydrology, erosion, and chemical response to land-use activities under different soil and climatic conditions. The uncertainty of model input and output is not defined in most applications, and modeling conclusions are generally stated in deterministic rather than probabilistic terms. While thoroughly acknowledged, model uncertainty is not defined in this research, and hypothesis testing of the effects of management treatments on model output assumes that output is representative of field observations.

RESEARCH OBJECTIVES

The research presented here was part of an interdisciplinary evaluation of the economic and water quality impacts of low-input sustainable agricultural (LISA) practices. Conservation tillage, crop rotations, residue use, nutrient management, and pest management are key components of low-input systems and BMPs. A modeling approach was taken to evaluate the relative effects of alternative combinations of these low-input components on nitrate leaching and pesticide losses in the Virginia Coastal Plain. While water quality impacts are the primary concern here, an economic evaluation of LISA alternatives/practices was the focus of a companion study (Diebel, 1990).

Specific objectives of the research presented here were:

1. Use selected NPS models to simulate the pesticide and nitrate pollution potential of existing and alternative crop management practices in the Coastal Plain region of Virginia.
2. Select and justify statistical procedures for comparing alternatives based on average annual loads predicted by the selected NPS models.
3. Use data generated by the models and statistical analysis to assess:
    a) Effect of tillage, crop rotations, and N application amounts and methods on nitrate leaching.
    b) Effect of tillage, crop rotations, chemical properties, and pesticide application practices on pesticide leaching and loads with surface runoff.

LITERATURE REVIEW: MODELING AGRICHEMICAL FATE AND TRANSPORT PROCESSES

Conceptualization of processes that affect nitrate and pesticide fate and transport in the unsaturated soil zone is a first step in NPS model development. Simplifying assumptions are necessary in the development of algorithms from concepts that describe component processes. A model user should interpret simulation results in light of concepts, assumptions, and limitations of a selected model. Concepts and model approaches to fate and transport processes of agricultural chemicals are reviewed, followed by a review of several comprehensive NPS management models, two of which were selected as suitable tools to accomplish the research objectives.

COMPONENT PROCESSES

Chemicals applied to the soil surface are lost via several pathways. Nitrogen fate and transport processes include leaching, plant uptake, volatilization, denitrification, and mineralization (Gilliam and Hoyt, 1987). Organic pesticide processes include leaching, adsorption, volatilization, and degradation/transformation reactions (Jury et al., 1983). Tillage and cropping systems affect the biological, physical and chemical parameters of the soil, which in turn affect the fate and transport processes of agrichemicals and their impacts on water quality (Dick and Daniel, 1987).

Adsorption

Adsorption is the adherence of chemicals to soil particles. It is a chemical- and soil-dependent process, which may be affected by crop management practices. Chemical concentration, soil pH, and soil organic matter are factors that affect adsorption. Adsorption of non-polar compounds occurs primarily on organic matter surfaces, and adsorption of polar compounds occurs primarily on clay surfaces (Smith et al., 1989). Most pesticides are non-polar, organic compounds. Chemicals which sorb to soil organic matter and clay particles tend to remain near the soil surface unless preferential flow paths are available for the transport of these particles through the soil. Moderately and poorly sorbed pesticides have a higher potential to reach groundwater depending on the amount and timing of water and chemicals (Donigian and Rao, 1986). Adsorption of NO_3^- depends on the anion exchange capacity of soils, and nitrate is generally poorly sorbed.

The linear and Freundlich isotherms are the main models used to describe pesticide adsorption-desorption on soils and sediments (Rao and Jessup, 1982). The equilibrium isotherms can be written as follows:

$S = K_d C$ (Linear)

$S = K_f C^N; N<1$ (Freundlich)

where S $[MM^{-1}]$ is the adsorbed-phase concentration, C $[L^3M^{-1}]$ is the solution phase concentration, K_d $[L^3M^{-1}]$ and K_f are adsorption coefficients, and N is an empirical adsorption isotherm constant. Equilibrium linear isotherms may be adequate over the range of solution concentrations associated with agricultural applications of pesticides (Rao and Davidson, 1980). The adsorption of pesticides is most affected by soil organic matter (Rao and Wagenet, 1984). The large variability in K_d and K_f due to adsorption by different soils can be reduced by normalizing the adsorption coefficient to the organic carbon content of the soil (Jury et al., 1983).

Degradation

Degradation refers to the change in structure or composition of the original organic compound through chemical and biological transformations. In the soil, microbiological processes dominate the degradation process when organic chemicals are present (Wagenet and Rao, 1985). Harmless inorganic end-products of microbiological degradation include H_2O and CO_2; however, organic metabolites may be produced that are more toxic than the original compound. First order, power rate, and hyperbolic models have been developed to simulate the loss of the original compound via degradation. The first order model is the most popular for field scale simulations (Rao and Jessup 1982). Its mathematical form is

$$Q = k\,(\theta C + \rho S)$$

The rate of degradation, Q $[ML^{-2}T^{-1}]$, can be set proportional to either the total pesticide concentration $(\theta C + \rho S)$, or to the solution phase concentration (θC). Where, S $[MM^{-1}]$ is the adsorbed phase concentration, C $[ML^{-3}]$ is the solution phase concentration, θ $[L^3L^{-3}]$ is the volumetric soil-water content, and ρ $[ML^{-3}]$ is the soil bulk density. The degradation rate coefficient, k $[T^{-1}]$, is mainly determined by environmental factors that support the microbial biomass, such as soil temperature and soil-water content (Rao and Jessup, 1982). Both factors are affected by management practices. Values for soil half-life of pesticides are inversely proportional to the rate coefficient which combines microbial degradation, hydrolysis, plus any other degradation process that may occur in the root zone. Considerable spatial lumping of k (or soil half-life) is unavoidable in field scale simulations (Leonard et al., 1987).

Microbial populations also play a major role in nitrogen cycling (Schepers, 1987). Denitrification is the reduction of nitrate to nitrogen gases by soil bacteria under anaerobic conditions. First-order reactions sensitive to organic carbon, temperature, and moisture are frequently used in modeling denitrification. Agricultural practices combined with seasonal conditions and climatic events will affect these factors. Moisture content, the most important factor in determining anaerobic conditions, must exceed field capacity for denitrification to be simulated by some models (Frere et al., 1980). Denitrification is generally not a major loss pathway of plant-available nitrogen relative to plant uptake, inputs of inorganic nitrogen, and mineralization of organic nitrogen.

Volatilization

Volatilization and vapor diffusion to the atmosphere are affected by Henry's Law constant, a chemical-specific parameter, and by other parameters such as soil temperature, soil-water content, organic matter content, and chemical concentration (Jury and Valentine, 1987). Volatilization is a major loss pathway for many pesticides, far exceeding losses in runoff and leaching, and second only to degradation in causing dissipation from treated fields (Glotfelty, 1987). The most important factor controlling pesticide and ammonia (NH_3) volatilization is the method of chemical application. Surface applications to no-till fields are highly susceptible to volatilization losses (Gilliam and Hoyt, 1987). Explicit volatilization components are generally not used in NPS management models, but foliar or surface half-life of pesticides can be representative of dissipation by volatilization, photolysis plus other processes. Simple algorithms that use foliar half-life and surface concentrations of pesticides have been incorporated in some models (Leonard et al., 1987; Carsel et al., 1985).

Mineralization

Nitrate can accumulate in the root zone as a result of mineralization and nitrification. Mineralization is the decomposition of organic forms of nitrogen to ammonium (NH_4^+) by microbes in the soil. Nitrification is the microbial oxidation of NH_4^+ to nitrite (NO_2^-) and nitrate (NO_3^-). The mineralization algorithm used in the CREAMS model lumps the entire conversion of organic N to nitrate into a single expression (Frere et al., 1980). Soil temperature, moisture content, potential mineralizable nitrogen and time are variables used in simple algorithms that calculate mineralized quantities of nitrogen. The portion of mineralizable organic nitrogen in field soils can be determined from a chemical test on soil samples, or estimated from the total N and organic carbon contents for various crops and soil types (Frere et al., 1980).

Plant Uptake

Pesticide uptake by plants is not well understood. It has been modeled as a function of environmental variables such as transpiration, soil-water matric potential, pesticide concentration, but verification is nearly impossible due to lack of field data (Wagenet and Rao, 1985). Some means of accounting for the upward redistribution of pesticides caused by plant uptake and/or evaporation processes is often developed by model builders to acknowledge that pesticide leaching is generally slowed by this process (Leonard et al., 1987).

Nitrogen uptake by plants is more adequately understood. Rates of nitrate uptake are affected by the following major factors: 1) the presence of ammonium, 2) nitrate concentrations at the root surfaces, and 3) the crop demand for nitrogen and the extent and distribution of the root system (Breteler et al., 1981). In the proceedings of a workshop, Simulation of Nitrogen Behaviour of Soil-Plant Systems, nine of the 15 models discussed have a component for plant uptake of nitrogen (Frissel and van Veen, 1981).

Leaching

Leaching refers to the downward movement of chemicals dissolved in the soil solution (Wagenet and Rao, 1985). Processes involved in solute transport through the soil are mass flow (advection/convection), molecular diffusion, and hydrodynamic dispersion (Wagenet and Rao, 1985; Rao et al., 1983). Leaching is principally determined by advection, which is in turn affected by tillage-dependent soil parameters including bulk density, porosity, pore size distribution, water content, soil temperature and chemical concentration (Onstad and Voorhees, 1987). Molecular diffusion and hydrodynamic dispersion will increase the volume that the solute occupies, thus decreasing the concentration in the unsaturated zone (Bouwer et al., 1988). Adsorption will slow the rate of chemical transport by decreasing dissolved chemical concentrations. Preferential flow through macropores may permit rapid, concentrated leaching of dissolved and adsorbed chemicals (Bevin and German, 1982).

Mechanistic or physically-based leaching models utilize some form of the convective-dispersive transport equation. The general form for steady water flow is:

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} - v \frac{\partial C}{\partial x}$$

where C $[ML^{-3}]$ is the solute concentration, D $[L^2T^{-1}]$ is the hydrodynamic dispersion coefficient, v $[LT^{-1}]$ is the pore water velocity, x [L] is vertical distance, and t [T] is time. Gish and Coffman (1987) successfully combined the general model with a stochastic model for the one-dimensional (vertical) velocity distribution to describe the movement of bromide through an established no-till corn field. Most of the variability associated with chemical dispersion can be attributed to the vertical water velocity regardless of the presence or absence of plants (Gish and Coffman, 1987; Addiscott and Wagenet, 1985). Addiscott and Wagenet (1985) report some indications that the presence of crop roots diminishes spatial variability in soil hydraulic properties. However, model representation of the spatial variability of field data remains a major issue to be resolved.

Daily records of water inputs and potential evaporation are required to develop models that utilize some form of the convective-dispersive transport equation. Furthermore, application of the equation with additional terms to describe physical, chemical, and biological interactions of agricultural chemicals with the soil-water regime is limited to laboratory experiments due to data-intensive requirements (Wagenet and Rao, 1985).

Simplified approaches to water and solute transport used in most field-scale and management-oriented models are based on the capacity of the soil to hold water, and "piston displacement" concepts (Wagenet and Rao, 1985; Rao and Jessup, 1982). The basic piston flow equation is:

$$Jn = Cn * Jw$$

where Jn [M] is the mass of nitrate leached below the root zone, Cn [ML^{-3}] is the concentration of solute in the root zone, and Jw [L^3] is the volume of percolating water. In addition to water inputs, soil parameters including field capacity, saturated moisture content, and the water content at the wilting point are often required. A simplified model for field-scale simulations has advantages in that it is easy to use, and necessary input data can be provided from existing databases (Rao and Jessup, 1982).

COMPREHENSIVE NPS MODELS

Research on the relative impacts of land-use practices on water quality has included the development of several comprehensive management-oriented models. The term "comprehensive" is used in the sense that agricultural management practices and their potential impacts on surface and groundwater are simulated through mathematical representation of several of the component processes described above.

NTRM

The Nitrogen Tillage and Residue Management (NTRM) Model is a field-scale, continuous simulation model that can evaluate the impacts of tillage, crop residues, irrigation, and nutrient inputs for impacts on erosion and short and long-term soil productivity as measured by crop yields (Shaffer, 1985). Nitrification, urea hydrolysis, and nitrogen immobilization are simulated by NTRM in addition to mineralization and denitrification. NTRM does not consider pesticides.

AGNPS

The Agricultural Nonpoint Source (AGNPS) Pollution model predicts runoff, sediment, and nutrient transport in surface runoff on an event basis. Output from individual cells can be used to identify critical areas and to evaluate alternative conservation practices for those areas (Young et al., 1987; 1989).

ANSWERS

The Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS) model is an event-oriented model that can be used as a planning tool to evaluate alternative nonpoint source pollution control strategies for their relative impacts on sediment transport in ungaged watersheds (Beasley and Huggins, 1982). Watersheds of up to 10,000 ha can be simulated by using a grid network of uniform cells usually having an area between 0.4 and 4 ha. This cellular breakdown of a watershed enables some accounting for spatially varying parameters such as topography, soils, land use, cover conditions, and rainfall intensity. A phosphorous transport component has been added to ANSWERS (Storm et al., 1988), and has been tested using data from the Nomini Creek Watershed which is in the Chesapeake Bay drainage basin. By targeting critical areas of the watershed for BMP implementation using cost-share funds, pollutant loading to surface water can be minimized. Thus, an efficient use of cost-share funds is facilitated by the application of ANSWERS to locate and treat areas of highest loadings.

CREAMS

Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS) (Knisel, 1980) has been widely used to assess alternative management practices for edge-of-field runoff, erosion, nitrogen and phosphorous loadings, and leaching of nitrate below the root zone (Williams and Nicks, 1988; Flanagan et al., 1986; Hubbard and Leonard, 1989; Nicks et al., 1984). Cost-effectiveness analyses of alternative nutrient management practices, such as manure spreading, split applications, and other methods of nitrogen application, have been done with CREAMS predictions that are linked to economic models (Heatwole et al., 1990; Roka et al., 1989; Crowder et al., 1985). Roka et al. (1989) ran CREAMS simulations using variable field slopes and soil textures. In their report, implementation and cost-effectiveness of BMPs for sediment control or nitrate percolation control are said to be influenced by the various soil factors that were simulated. Thomas et al. (1990) performed one-way analyses of variance on long-term CREAMS and GLEAMS predictions to evaluate effects of rapeseed production alternatives on pollution potential in the Georgia Coastal Plain. Significant conclusions from their analyses of variance were followed by Duncan's multiple range tests to find the significant differences in runoff, erosion, and nutrient and pesticide losses resulting from different soil types, slopes, planting dates, and split nutrient applications.

GLEAMS

Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) is a field-scale hydrology and pesticide transport model (Leonard et al., 1987). The GLEAMS surface hydrology and erosion components are based on the CREAMS model. GLEAMS can accommodate depth-variable hydrology parameters for up to 5 soil horizons in the root zone to distinguish differences in porosity, organic matter, field capacity, and wilting point (Davis et al., 1990). GLEAMS allows multiple applications of pesticides per year, and up to ten pesticides plus metabolites can be simulated simultaneously. Pesticide leaching is predicted at the bottom of the root zone, and losses with runoff and erosion are predicted at the edge of the field area being simulated.

GLEAMS applications show the partitioning of pesticides and their metabolites into surface runoff, sediment, and percolation as a result of agricultural and pesticide management practices (Hubbard et al., 1989). Knisel et al. (1989) simulated distinct class limits for pesticide half-life and adsorptivity, the two primary properties that affect surface and leaching losses. Other variables considered were planting dates and irrigation scheduling. Results of the GLEAMS simulations generally supported the assertion that the ratio of pesticide half-life to mobility is a useful indicator of leaching potential (Leonard and Knisel, 1988a). Leonard and Knisel (1989) used GLEAMS to show that controlled release pesticides, as compared to conventional formulations, are likely to provide greatest benefits in reducing leaching of short half-life compounds applied to sandy soils.

PRZM

The Pesticide Root Zone Model (PRZM) is a field-scale, continuous simulation model designed to simulate the effects of agricultural management practices on pesticide fate and transport (Carsel et al., 1984; 1985). PRZM has a hydrology component, and a chemical component that simulates plant uptake, foliar washoff, volatilization, degradation, adsorption, and leaching. PRZM allows only one application of pesticides per year. Leaching of pesticides is predicted through the vadose zone, providing an estimate of groundwater loading.

Bretas and Haith (1990) used PRZM to estimate pesticide leaching coefficients for cropping activities involving potato farming on Long Island, New York. The coefficients were used in a linear programming model developed to assess the economic impacts of enforcement of pesticide groundwater quality standards.

GENERAL LIMITATIONS OF MODELING

Validation of results is a basic concern in applications of NPS management models. Spatial variability, incomplete field data bases, and inadequate mathematical representation of the physical system may limit the success of validation at the outset. The uncertainty of absolute predictions is acknowledged in most studies. Management-oriented, deterministic models were designed to show *relative* differences in water quality response to management practices. However, even model results that show relatively different water quality response to management practices may not be consistent with available field observations.

Spatial and temporal variability in field or watershed soils are realities of the physical system that have not been fully captured in model development and application. Spatial variability refers to changes in a soil property, such as bulk density, water content, total porosity, hydraulic conductivity, organic carbon content, etc. over the field area, and also with depth at a given location (Rao and Wagenet, 1984). Temporal variability refers to changes in properties with time. Variability is usually considered to be the combined result of extrinsic and intrinsic factors (Rao and Wagenet, 1984). Extrinsic factors that contribute to variability include a number of field management treatments, such as tillage, irrigation, and pesticide and fertilizer applications. Intrinsic variability refers to natural variations in physical, chemical, and biological properties of field soils (Rao and Wagenet, 1985). Borah and Haan (1989) acknowledge modeling error due to spatial variability and other factors by imposing error distributions on precipitation and input parameters used in the USGS Precipitation Runoff Modeling System (PRMS). A change from deterministic modeling approaches to stochastic ones is necessary to account for variabilities in the physical system. A stochastic treatment of individual components in the models selected for this research was not pursued.

Increasingly complex models of fate and transport processes and stochastic interactions between components are indeed being formulated. Nevertheless, Rao and Jessup (1982) suggest that simpler models may actually be more appropriate and equally accurate for field scale simulations. Data for simpler models is more easily obtainable, validation may be relatively thorough, and the user is more likely to apply the models to situations for which they were developed (Rao and Jessup, 1982). The models that were reviewed for this research are comprehensive, but they all simplify to a greater or lesser degree otherwise complex component processes whose varying influences combine to determine the fate and transport of applied chemicals. Assuming that model sensitivities are realistic, the relative sensitivity to each component determines what data should be carefully obtained, and the likelihood of successful validation.

PROCEDURES

Richmond County was selected as a study area representative of the Coastal Plain region of Virginia. Soil, topographic, and climatic characteristics of the county were available. Data for typical agricultural operations in the county were also accessible.

SITE DESCRIPTION

Important land-use, soil, and topographic characteristics of the study area (Richmond Co., Va.) were obtained from Shanholtz (1989) and from the county soil survey report (USDA-SCS, 1983). The information indicates that land-use in Richmond County is approximately 21.1% cropland, 16.5% deciduous woodland, 8.0% coniferous woodland, 1.1% pasture, and 20.5% non-agricultural, non-woodland. One-third of the cropland is on Suffolk-sandy loam soil, and of this, 17.5% has 0 to 2% slope and 16.8% has 2 to 6% slopes. Other major cropland soils and slopes include: 8.9% Tetotum fine sandy loam (0 to 2% slopes), 6.7% Emporia loam (2 to 6% slopes), 6.3% Rumford loamy sand (0 to 6% slopes), and 4.2% Kempsville loam (0 to 2% slopes). All of these soils are grouped with Suffolk in the major soil associations in the county, but many soil properties that effect chemical movement to groundwater, including hydraulic conductivity, may be quite different between the soil types.

A survey of 30 farm operators in Richmond County (Diebel, 1990) provided information on current cropping systems and practices, and served as the basis for the alternative management practices evaluated in this research. Four basic crop rotations are used in the county: a) Conventional tillage (CT) corn, CT wheat - double-cropped with no-till (NT) soybeans (2 years); b) CT corn, CT wheat - double-cropped with NT soybeans / CT full-season soybeans, CT wheat - double-cropped with NT soybeans (4 years); c) NT corn, CT wheat - double-cropped with NT soybeans, rye winter cover (2 years); and d) NT corn, CT wheat - double-cropped with NT soybeans, rye and clover winter cover (2 years). Area farmers generally apply commercial nitrogen, phosphorous, and pesticides (mostly herbicides) following Extension Service recommendations.

MANAGEMENT SCENARIOS

Using the basic cropping systems above, 40 rotations that combine different tillage-cultivation practices, fertilization sources and application amounts, and pesticide types and application amounts were defined (Diebel, 1990). Table 1 lists these combinations. The 40 rotations represent nine tillage-cropping practices. The nine practices include the 4 basic crop rotations and five alternative rotations with different tillage-cultivation methods: NT corn planted in soybean residue (no winter cover after soybeans), chisel-plant corn, disk-plant corn, and additional cultivations for weed control in 2 rotations. Thirty-one of the rotations represent tillage-cropping and nutrient management combinations. On the 9 tillage-cropping practices, either high, medium, low, or no pesticides were applied as means for pest management. Nine additional rotations were defined for 3 alternative pesticide management techniques combined with 3 of the tillage-cropping practices.

Table 1. General Description of Management Activities

Rotation	Year	Tillage-Cropping Practices[a]	Nutrient Mngmt. Alternatives[b]	Special Management Conditions[c]
1	1	CT-plant corn, CT-plant wheat	1,2,3,4	medium chemicals
	2	NT-plant soybeans		
4		"	1,3	3-way split N applications
6		"		2,4-D and Bladex for Aatrex
7		"		Lasso for Dual
17		"		Roundup for Gramoxone
2	1	NT-plant corn, CT-plant wheat	1,2,3,4	high chemicals
	2	Disk-plant soybeans		
3	1	Chisel-pl. corn-Cultivate 1x, CT-pl. wheat	1,2,3,4	low chemicals
	2	NT-plant soybeans		
5	1	Disk-plant corn-Cultivate 3x, CT-pl. wheat	2,4	no chemicals
	2	NT-plant soybeans-Cultivate 3x		
8	1	NT-plant corn-Cultivate 1x, CT-plant wheat	1,2,3,4	medium chemicals
	2	NT-plant soybeans, rye WC		
9		"		2,4-D and Bladex for Aatrex
10		"		Lasso for Dual
18		"		Roundup for Gramoxone
11	1	NT-plant corn-Cultivate 3x, CT-plant wheat	2	no chemicals
	2	NT-plant soybeans-Cultivate 3x, rye WC		
12	1	CT-plant corn, CT-plant wheat	1,2,3,4	medium chemicals
	2	NT-plant soybeans		
	3	CT-plant soybeans, CT-plant wheat		
	4	NT-plant soybeans		
13		"		2,4-D and Bladex for Aatrex
14		"		Lasso for Dual
19		"		Roundup for Gramoxone
15	1	Disk-plant corn, CT-plant wheat	1,2,3,4	medium chemicals
	2	NT-plant soybeans, rye & clover WC		
16	1	Disk-plant corn-Cultivate 3x, CT-pl.wheat	2,4	no chemicals
	2	NT soybeans-Cultivate 3x, rye & clover WC		

[a] CT = Conventional Tillage, NT = No-Tillage, WC = Winter Cover

[b] Nutrient Management Alternatives:
1-Commercial N and crop residue
2-Poultry litter and crop residue
3-Commercial N ignoring crop residue
4-Poultry litter ignoring crop residue

[c] 'medium chemicals' is the recommended nitrogen and pesticide application rate

Four different nutrient management scenarios were evaluated: 1) commercial fertilizer applications reduced to account for N supplied by crop residue; 2) commercial fertilizer replaced with poultry litter with crop residue N also considered; 3) commercial fertilizer at rates that do not account for N supplied by crop residues; and 4) commercial fertilizer replaced with poultry litter, with no accounting for N supplied by crop residues. Commercial N in scenarios 1 and 3 was applied in 2-way splits, except on rotation 4 which used 3-way split applications for wheat. Poultry litter in scenarios 2 and 4 was applied once prior to planting corn and wheat. Details of nitrogen and application amounts and methods are given in Appendix A. Nitrogen in poultry litter was divided into organic and inorganic components. The organic fraction that was mineralizable and potentially available for crop utilization was considered to be an additional source of inorganic (plant-available) nitrogen.

Rotations 5, 11, and 16 (Table 1) only involved the use of poultry litter (scenarios 2 and 4). Rotation 4 used only commercial N (scenarios 1 and 3) in 3-way split applications. For all other rotations under a particular tillage-cropping practice, all four nutrient management scenarios were evaluated. For example, for conventional-tilled rotations (1, 6, 7, and 17) under nutrient management scenario 1, commercial N was applied in 2-way splits of 27 and 100 kg/ha to corn, and 5 and 80 kg/ha to wheat. For scenario 2 (rotations 1, 6, 7, and 17), one pre-plant application of poultry litter replaced the commercial N application and supplied 76 kg/ha of organic N and 51 kg/ha of inorganic N for corn, and 51 kg/ha organic and 34 kg/ha inorganic N for wheat. In scenario 3 (rotations 1, 6, 7, and 17), commercial N was applied in a 2-way split of 44 and 112 kg/ha to corn, and 17 and 73 kg/ha to wheat. Finally, for scenario 4 (1, 6, 7 and 17), one pre-plant application of poultry litter replaced the commercial N application and supplied 88 kg/ha of organic N and 58 kg/ha of inorganic N for corn, and 54 kg/ha organic and 36 kg/ha inorganic N for wheat. Total N applied per rotation was always equivalent between scenarios 1 and 2, and between scenarios 3 and 4. Increases in N application amounts from scenarios 1 and 2, to scenarios 3 and 4 within rotations, ranged from an average 4 to 25 kg/ha/yr. Application amounts for the same scenarios between rotations under different tillage-cropping practices varied by up to an average of 65 kg/ha/yr. Appendix A contains a listing of nitrogen application and tillage-cropping schedules for all rotations. (Long-term average N application rates are listed in Table 9.)

Rotation 2 had high amounts of nitrogen applied for all scenarios compared to rotations 1, 4, and 5, which had recommended (medium) amounts of N applied for scenarios 1 and 2. Application amounts were relatively low on rotation 3. Rotations 8 and 11 had rye winter cover which provided a small increase in supplemental nitrogen to the following corn crop, but N was still applied to corn at amounts that were relatively high for any scenario compared to those of rotation 1. On rotations 15 and 16 nitrogen was applied according to recommendations for scenarios 1 and 2 to include the nitrogen provided by clover in winter cover crops that were planted in these rotations. N application amounts were increased an average 25 kg/ha/yr for scenarios 3 and 4 when the N contribution of clover was ignored. Rotation 12 was the 4-year rotation, and N application rates for corn and wheat for scenarios 1 and 2 were comparable to rotation 1. However, corn was planted only once every four years, so long-term average application rates were up to 65 kg/ha/yr less than for scenarios 1 and 2 compared to other rotations.

Thirty-one of the 34 rotations include pesticide applications, with a total of fifteen pesticides used between all rotations. Table 2 summarizes pesticide application rates and pesticide properties that strongly influence fate and transport processes. Rotations 5, 11, and 16 had no pesticides applied. Half-life and adsorption depend strongly on site-specific soil conditions. Variable conditions, in addition to different experimental methods, lead to reported values of K_{OC} and half-life that may vary by a factor of 2 or 3 for the same pesticide (Leonard et al., 1986). For example, reported half-lives of Atrazine range from about 20 to 100 days depending on soil and depth.

Table 2. Pesticide Properties[a] and Application Characteristics used in Simulations

Trade Name	Common Name	Solubility (ppm)	Soil Half-life (days)	K_{oc}	APPLICATION Rate: Rotations; Crop[b] (kg-AI/ha)[c]
Aatrex	Atrazine	33	60	160	1.69: 1,3,7,8,10,18,12,15,14,17,19; Corn
					2.25: 2; Corn
Dual	Metolachlor	530	20	200	1.13: 1,17,19; Corn & Beans; 6,18 Beans only
					1.13: 15; Corn only
					0.56: 6; Corn
					0.32: 2; Corn
					2.25: 8,9,12,13,18; Corn
					1.69: 12,13,19; FS Beans; 15; Beans
Gemini	Chlorimuron	500	50	20	0.02: 1,6,7,17; Beans; 12,13,14,19; FS Beans
	+ Linuron	75	60	863	0.20: " " " "
Gramoxone	Paraquat	1.0E6	3600	1.0E5	0.32: 2; Corn
					0.53: 1,2,6,7,8,9,10,12,13,14,15; Beans
					0.18: 3; Beans
Harmony	DPXM-6316	2400	12	10	0.03: 1,2,6,7,17,8,9,10,18,12,13,19,15; Wheat
2,4-D	2,4-D(amine)	900	10	74	0.56: 6,9,13; Corn
					0.28: 2; Wheat
Lasso	Alachlor	242	14	190	2.25: 7,10,14; Corn
Bladex	Cyanazine	171	20	168	1.80: 6,9,13; Corn
Fusilade	Fluazifop-P	2	20	3000	0.22: 1,3,6,7,8,9,10,12,13,14,15,17,18,19; Beans
Pydrin	Fenvalerate	0.1	50	1.0E5	0.15: 1,2,6,7,8,9,10,12,13,14,15,17,18,19; Beans
Blazer	Acifluorfen	9.0E5	30	139	0.42: 2,8,9,10,18,12,13,14,19,15; Beans
Banvel	Dicamba	8.0E5	14	2	0.28: 2; Wheat
Roundup	Glyphosate	1.0E6	30	1.0E4	1.13: 2,17,18,19; Beans; 12,13,14,19; FS Beans
Treflan	Trifluralin	0.3	60	1400	0.85: 12,13,14,19; FS Beans
Lorox	Linuron	75	60	863	0.56: 2,8,9,10,18,12,13,14,19,15; Beans

[a] Sources: Davis et al. (1990), Wauchope (1988), Royal Soc. of Chem. (1987), and Verschueren (1983)
[b] 'Beans' refers to double-crop soybeans after wheat. 'FS Beans' = full-season soybeans
[c] AI = Active Ingredient

Several alternative pesticide management practices in combination with the tillage and cropping practices were evaluated. Special management conditions in Table 1 particular to pesticides include substitution of pesticides for others, and high, medium, low, and no application amounts. "Medium chemicals" refers to pesticide applications at recommended amounts. "High chemicals" used in rotation 2 includes a 33% greater amount of atrazine applied to corn and a greater number of pesticides applied per crop than would generally be recommended. For rotation 2, paraquat was applied prior to planting corn in addition to atrazine and metolachlor, and 2,4-D and dicamba were applied to winter wheat in addition to DPXM-6316 (Table 2). Low chemicals (rotation 3) includes the use of fewer pesticides as well as gramoxone applied before planting beans at a much lower rate than recommended. Atrazine and fluazifop-P were the only other pesticides used in rotation 3.

Effects of substituting alternative pesticides having similar weed control characteristics but different chemical properties were evaluated for possible tradeoffs between surface and groundwater impacts. 2,4-D and cyanazine were applied prior to planting corn on rotations 6, 9, and 13 as a substitute for atrazine. Alachlor was applied prior to planting corn on rotations 7, 10, and 14 as a substitute for metolachlor. And, glyphosate was used to kill winter wheat before planting soybeans on rotations 17, 18, and 19 as a substitute for paraquat.

MODELING APPROACH

After reviewing NPS management models that were potentially applicable to the objectives of this research, CREAMS was selected to simulate hydrology, erosion, and nitrate leaching. CREAMS has been widely applied and tested. Assumptions, simplifications, and mathematical representation of component processes are thoroughly documented for the

CREAMS model. The selection of GLEAMS for consideration of pesticide transport followed naturally because the surface hydrology and erosion components of GLEAMS and CREAMS are alike.

Average annual nitrate and pesticide loads were the desired model outputs. Using statistical tests on average loads, relative comparisons were made on the effects of different crop rotations, tillage, and nutrient and pesticide management practices. In this comparative mode, little calibration was necessary. Procedures for obtaining and evaluating model output are described in the following sections.

Model simulations were run for 35-years using historical climatic data for Richmond County obtained from the Warsaw weather station. The data included daily precipitation, and monthly average temperature and solar radiation for a 35-year period (1951-1985). A monthly and annual summary of precipitation data is in Appendix B.

CREAMS/GLEAMS Hydrology and Erosion Components

Soil related parameters were based on Suffolk sandy loam soil at 3% slope. CREAMS and GLEAMS are field-scale models, and assume spatially uniform soil and landuse conditions. A field limited in area to 0.4 ha (1 acre) was represented in the simulations. Predictions are made on a unit area basis. Important soil and management related parameters for the CREAMS and GLEAMS hydrology and erosion components are listed in Tables 3 and 4. The same hydrology and erosion parameters were used in both models, and hydrology and erosion outputs from the two models were equivalent. Only rotations with different tillage-cropping practices were "hydrologically different" from others. CREAMS and GLEAMS runoff and erosion parameter files for each of the nine hydrologically different rotations are listed in Appendix C. Table 3 and 4 values for DACRE, RC, RD, UL(1-7), BOTHOR, SLNGTH, and KSOIL were read in English units in the parameter files.

Table 3. Selected Hydrology Parameters and Values used in the Simulations*

Para-meter	Definition	Rotation# 1	2	3	5	8	11	12	15	16
DACRE	Drainage area (hectares)			0.40			(all rotations)			
RC	Effective saturated hydraulic conductivity (cm/hr)			0.71			(all rotations)			
FUL	Fraction of pore space filled at field capacity. CREAMS only			0.44			(all rotations)			
CONA	Soil evaporation parameter			3.5			(all rotations)			
POROS	Soil porosity (cm^3/cm^3)			0.40			(all rotations)			
BR15	Wilting point (cm/cm)			0.08			(all rotations)			
CN2	SCS curve number for moisture condition II	80	77	78	79	76	78	81	77	79
CHS	Field slope (m/m)			0.03			(all rotations)			
WLW	Watershed length to width ratio			1.5			(all rotations)			
RD	Effective rooting depth (cm)			76.2			(all rotations)			
UL(1-7)	Total soil water storage (cm) for each of seven soil layers. CREAMS only		UL(1) = UL(2) = UL(3-7) =	0.69 3.38 4.06			(all rotations) (all rotations) (all rotations)			
NOSOHZ	Number of soil horizons in the root zone GLEAMS only			2			(all rotations)			
BOTHOR	Depth to bottom of each soil horizon (cm)			45.7 and 76.2			(all rotations)			
FC	Field capacity			0.22 and 0.22			(all rotations)			
OM	Organic matter content (% of soil mass)			1.0 and 1.0			(all rotations)			
LDATE	Dates (Julian days)		Varies with crops grown, and planting and harvest dates for each rotation							
AREA	Leaf area index for the crops grown		Varies with LDATE for each rotation							

* Sources: USDA-SCS (1983) and Soil Conservation Service (1984)

\# Rotation: 1 also represents rotations 4, 6, 7, and 17
2 also represents rotations 9, 10, and 18
12 also represents rotations 13, 14, and 19

Table 4. Selected Erosion Parameters and Values used in the Simulations*

Parameter	Definition					Rotation#				
		1	2	3	5	8	11	12	15	16
SOLCLY	Fraction of clay in surface soil layer			0.15			(all rotations)			
SOLSLT	Fraction of silt in surface soil layer			0.25			(all rotations)			
SOLSND	Fraction of sand in surface soil layer			0.60			(all rotations)			
SSCLY	Specific surface area of clay particles (m^2/g)			20.0			(all rotations)			
SSORG	Specific surface area of organic matter (m^2/g)			1000.0			(all rotations)			
SLNGTH	Slope length (m)			61.0			(all rotations)			
KSOIL	Soil erodibility factor (Mg/ha)			0.48			(all rotations)			
NYEARS	Number of years in the rotation	2	2	2	2	2	2	4	2	2
CDATES	Julian days on which the next three sets of parameters take effect		Varies with cropstage and tillage practices through each NYEARS of a rotation							
CFACT	Soil loss ratio of overland flow segment		Varies with CDATES for each rotation							
PFACT	Contouring factor		1.0 on all CDATES, all rotations, indicating no contouring or terraces used							
NFACT	Nanning's n (surface roughness coeff.)		Varies with CDATES for each rotation							

* Sources: USDA-SCS (1983) and Soil Conservation Service (1984)

\# Rotation: 1 also represents rotations 4, 6, 7, and 17
2 also represents rotations 9, 10, and 18
12 also represents rotations 13, 14, and 19

CREAMS Nutrient Component

CREAMS (WCC version) was used to predict nitrate in runoff and leachate. Important parameters of the CREAMS nutrient component are listed in Table 5. A complete listing of nutrient parameter files for each nutrient management scenario is in Appendix D.

CREAMS takes a simplified approach to nitrogen dynamics. Piston flow of nitrate dissolved in soil-water is assumed. Molecular diffusion and hydrodynamic dispersion are not simulated. Uptake of N by the crop is simulated as a function of plant transpiration and plant available N concentration. Denitrification is simulated as a first order reaction affected by organic carbon, temperature and water content (Knisel, 1980). Mineralization rate of organic nitrogen is adjusted for temperature by an exponential function, and for water content by a linear function. Organic N from poultry litter and crop residues that would be mineralized was added as potential mineralizable nitrogen (POTM). For this study, CREAMS was modified so that the POTM parameter added to, rather than replaced, the value of the POTM state variable at the time of input (Heatwole, 1990). POTM varied substantially with different crop residues and nitrogen management scenarios. POTM input values and dates are listed in Appendix A. Diebel (1990) provided data for organic nitrogen in crop residues and poultry litter. For poultry litter scenarios, 60% of the nitrogen applied was mineralizable organic N, while 40% of the nitrogen was already in the inorganic state.

Table 5. Selected CREAMS Nutrient Parameters and Values used in the Simulations*

Parameter	Definition	Value for all Rotations
SOLN	Soluble nitrogen (kg/ha) in surface 1 cm	0.2
NO3	Nitrate (kg/ha) in root zone at start of simulations	20.0
SOILN	Total soil nitrogen (kg/kg) in surface 1 cm	0.002
EXKN	Extraction coefficient for nitrogen	0.07
AN	Enrichment coefficient for nitrogen	7.4
AP	Enrichment exponent for nitrogen	-0.2
RCN	Concentration (ppm) of nitrogen in rainfall	0.8

* Source: Soil Conservation Service (1984)

GLEAMS Pesticide Component

GLEAMS (version 1.8.55) was used to predict pesticide loads in runoff and leachate. The model simulates pesticide fate through degradation (first-order), adsorption (reversible, equilibrium linear isotherm), evaporation, foliar washoff, and plant uptake (passive with plant transpiration) (Leonard, 1986). Pesticide solubility, half-life, and the adsorption coefficient (K_{OC}) are the most important GLEAMS parameters because persistence, mobility, and the partition of pesticides into surface runoff, sediment, and percolation depend on these parameters. The parameter values in Table 2 were used in the simulations. Complete pesticide input files for all management practices are in Appendix E.

EVALUATING CREAMS AND GLEAMS MODEL OUTPUT

Important issues were confronted in this study regarding parameter lumping and process and sensitivity imbalances in the CREAMS and GLEAMS models. Some process imbalance undoubtedly exists in the models (Ferreira and Smith, 1989). For example, the erosion component uses a modified Universal Soil Loss Equation with built in complexities that sort sediment according to size fractions (Knisel, 1980), yet the erosion component is driven by output from the relatively simple hydrology component which uses the SCS runoff equation.

CREAMS and GLEAMS are continuous, daily simulation models; however, many parameters have to be averaged over an entire rotation and input as fixed values. The most important parameter in this regard is the SCS curve number because the CREAMS/GLEAMS hydrology component is highly sensitive to the curve number. The retention parameter (S) used in the runoff equation is calculated from soil moisture and the fixed curve number, and is updated internally as a function of changing soil moisture.

However, the adjustments to S are not sufficient to reflect changes in crop and soil cover conditions that occur over crop sequences.

The problems caused by high model sensitivity to the fixed SCS curve number had implications for validation and statistical procedures. Consider that an average curve number was selected for each of the two-year rotations. For two rotations that had identical conditions in one year, a difference in practice during the second year resulted in different average curve numbers between the two rotations. Thus, model output: runoff, erosion, and contaminant transport, could be significantly different between rotations, even for the one year that had identical treatment. However, the difference in output between one year of the rotations was offset by less significant differences in the second years of the rotations where the treatment differences actually occured. As a result of imbalanced model sensitivity to the SCS curve number that is not offset by internal adjustments to S, average output for all years over each rotation had to be used in any comparative analysis of output, not individual years.

Calibration and Validation

Hydrology

For initial simulations, 35-year average CREAMS and GLEAMS runoff predictions ranged from 2.8 to 4.1 cm/yr or 3 to 4% of average annual precipitation over all rotations. An effort was made to validate hydrology output with reported observations from Coastal Plain areas having soils similar to the Suffolk sandy loam. Data from two gaging stations in the Nomini Creek watershed provided an estimate of runoff from Coastal Plain watersheds (Mostaghimi et al., 1989). Visual hydrograph separation was used to estimate base flow and storm runoff at two watershed gauging stations, QN1 and QN2. QN2 is located at the outlet of a 225-hectare sub-watershed, and QN1 is the outlet of a 1500-hectare watershed. In 1987, 11.9 cm of storm runoff was observed at QN2 which was 12.7% of recorded precipitation. In 1988, QN2 recorded 6.4 cm of storm runoff or 6.6% of precipitation. Storm runoff at QN1 was 4.8 and 6.9 cm or 5.2 and 7.0% of precipitation in 1987 and 1988, respectively. Surface runoff may be considerably less than storm runoff because a portion of the latter is derived from shallow interflow.

In a Coastal Plain region at Tifton Georgia, a 0.34 ha watershed under a rotation of winter rye, sweet corn, and pearl millet yielded surface runoff of 7 cm/yr or 6% of precipitation (Hubbard and Leonard, 1989). In that study, CREAMS was used, and its predictions for surface runoff were less than what actually occurred. Surface crusting of the sandy Coastal Plain soil, a process not represented by CREAMS, may account for the greater actual runoff (Hubbard and Leonard, 1989). Also, problems inherent to the curve number approach which the model uses, may cause predictions of the initial abstraction to be too high; and thus, runoff predictions to be too low for some areas (Shirmohammadi and Williams, 1987).

On the basis of the available information presented above, runoff predictions were calibrated by increasing the averaged SCS curve number by 2 or 3 on all rotations depending on specific differences in tillage and cultivation practices. The result was an increase in runoff to final values of 3.4 to 5.6 cm/yr or 3 to 5 % of average annual precipitation.

Nutrients

Validation of nutrient output from the simulations with reported observations was limited by the availability of data in the literature. Differences in predicted and reported observed results due to geographic location, crop rotations, tillage, and fertilizer and pesticide application amounts, also made quantitative validation difficult. Hubbard and Leonard (1989), in a 0.34 ha watershed study at Tifton Georgia, report a range of soil nitrate from 11.3 to 140.7 kg/ha (cumulative to 30 cm soil depth) over 11 months (10 sampling times) under a rotation of winter rye, sweet corn, and pearl millet. An average of 142 kg/ha/yr of commercial N was applied to sweet corn during the sampling period. CREAMS, in that report, predicted 0.0 to 97.3 kg/ha soil nitrate. For rotation 2 in the current study, monthly output from CREAMS for a 30 cm soil depth and nitrogen applications to corn of 150 kg/ha/yr showed a range of soil nitrate over 12 months from 6.1 to 106.3 kg/ha. If CREAMS predictions of soil nitrate are generally low, as could be inferred from the predictions in this study and in the cited report, then the model apparently leaches nitrate out of the root zone faster than what actually occurs (Hubbard and Leonard, 1989).

Hubbard and Leonard (1989) indeed report greater CREAMS predicted leaching of nitrate than actual nitrate loads in subsurface flow over a 17-month period. Actual loads ranged from 0 to 7.95 kg/ha, while predicted nitrate leaching was from 0 to 68.6 kg/ha over the 17-month period. The predicted nitrate leaching on a monthly basis in this study was less than that predicted above, ranging from 0 to 20.1 kg/ha for rotation 2.

Hubbard and Leonard (1989) also reported that actual and CREAMS-predicted nitrate loads in surface runoff were quite low from the sandy Coastal Plain soil. In a previous study on the same watershed, Hubbard and Sheridan (1983) reported a ten year mean NO_3 concentration in surface runoff of 0.47 mg/L. A rough conversion to average nitrate loading with surface runoff gives 0.33 kg/ha/yr using observed average surface runoff of 7 cm/yr from the 0.34 ha watershed. For this study, average predicted nitrate loads ranged from 0.32 to 0.70 kg/ha/yr over all nine tillage-cropping practices.

Pesticides

Leaching and surface loss predictions for pesticides were highly sensitive to chemical adsorption coefficients, solubilities, and soil half-lives. Validity of GLEAMS output was difficult to define because of variability in reported parameters and lack of field data on all 15 pesticides used in the simulations. Chemical fate and transport processes, such as storage, adsorption, and degradation that occur between the root zone and groundwater are not accounted for in GLEAMS. In a GLEAMS application, Leonard et al. (1986) reported that less than 10% of predicted leaching losses of atrazine were actually transported out of the study area in shallow groundwater. Shirmohammadi et al. (1987) reported in another GLEAMS application that leachate concentrations of atrazine and metolachlor from the bottom of the root zone were about 3-7 times higher than the average concentrations found in groundwater.

Leonard et al. (1986) incorporated 1.65 kg/ha atrazine to 15-cm depths on a Bonifay sand in the southeastern Coastal Plain (Ga.) on 124 m^2 plots planted to sweet corn. Negligible surface runoff was observed from the plots. In the second year of the 3-year experiment 0.694 g of atrazine was measured in total subsurface discharge. This was somewhat greater than the average 0.23 g of atrazine calculated from predicted values for the current study where the same amount of atrazine was used for corn. However, long-term application rates in this study were less because corn was planted only in every other year of the 2-year rotations. Observed atrazine losses to groundwater were much less in the second and third years of the Georgia study (Leonard et al., 1986).

Shirmohammadi et al. (1987) did a 3-year field and GLEAMS simulation study of paired watersheds under no-till (NT) and conventionally tilled (CT) corn on Metapeake silt loam in the Coastal Plain physiographic region of Maryland. Cyanazine, atrazine, metolachlor, and dicamba were surface applied at 2.24, 1.68, 1.68, and 0.55 kg/ha, respectively. Measured runoff from the NT watershed was greater than from the CT watershed in two out of three years. This was contrary to GLEAMS predictions. However, runoff from the NT watersheds was much less (5.0 cm) than from the CT watershed (16.5 cm) in the first year, which was a relatively high rainfall year (102.8 cm). Three-year average precipitation was 90.6 cm which was less the 35-year average of 109 cm for the current study. GLEAMS underpredicted surface runoff from both watersheds in all years of the former study. In the first year, for example, GLEAMS predicted 3.06 cm runoff from the NT watershed and 4.82 cm from the CT watershed.

Percolation losses of cyanazine, atrazine, metolachlor, dicamba, and two other pesticides were evaluated in the study cited above. Observed, individual pesticide losses by percolation were highly variable between years of that study. Percolation losses of pesticides were slightly greater from the conventional watershed than from the no-till watershed for all years. Average observed percolation losses for both watersheds over the 3-year study period were 0.128, 1.16, 0.691, and 0.073 kg/ha/yr for cyanazine, atrazine, metolachlor, and dicamba, respectively. In the current study, average predicted percolation losses of cyanazine, atrazine, metolachlor, and dicamba were 0.005, 0.575, 0.005, and 0.595 kg/ha/yr, respectively. Long-term average application amounts were lower in the current study because herbicides were only applied every other year.

Statistical Procedures

Justification

An analysis of the CREAMS and GLEAMS model output was pursued in a context analogous to a field experiment. From this viewpoint, the simulations represent a deterministic field experiment. For a given set of climatic input and parameters, the model output is fixed. Every parameter and model algorithm that affects output is identifiable.

In reality, it is not possible to have a deterministic field experiment (there is variance associated with each observation). Field data reflect the nature of the physical system plus error. Modeling the system, parameter estimation, calibration, and validation of output, all rely on field data, whether the model components are physically based or completely empirical. Uncertainty in field observations are not reflected in tabulated parameter estimates that are provided to the model user. It follows that variability in parameters cannot be reflected in conclusions about model output. Thus, a deterministic approach was maintained for the procedures developed here, with daily precipitation being the only stochastic input.

The goal here was to select an appropriate statistical analysis to test land-use treatment effects on model output as if model output were analogous to field observations. Treatments were represented in the model by different sets of management-related parameters. In a field experiment, several homogeneous plots having identical soil conditions would be assumed. Next, management practices would be randomly assigned to plots. In the field, replication and randomization is good practice, but it is not necessary, and not possible, in a deterministic model. Thus, each management practice was simulated only once, and in the analogous field experiment, only one plot for each practice would be needed. The combined practice factors on each plot - different from one plot to the next - interact to produce different water quality response. Some of these factors were specifically defined treatments in the model simulations. Different, but related treatments were isolated with other factors being equal. Hypothesis tests were done to find potentially significant differences between treatment effects on water quality response.

The field plots would be continuously affected by environmental phenomena, and water quality responses would vary most obviously with precipitation. Because of this strong dependence on precipitation, plot responses from one plot to the next, under related treatments that are applied at the same time, would show a dependence on each other. Thus, a two-way block layout was recognized as being an effective statistical procedure to filter out the single largest source of variability - precipitation, and to find significant treatment effects on water quality. Treatments applied at identical times between field plots would trigger plot responses (model predictions) that do not differ by the same amount at all times, as might be expected in the deterministic design. In fact, the variability in annual response differences between two or more plots would be analyzed. Hence the term "statistical sensitivity analysis" became meaningful as applied to model output representing field plots.

In a sensitivity analysis, model sensitivity depends on the base set of parameters and the base precipitation input. For given base values, the sensitivity of a given output variable is fixed for a given change in the base set of parameters. (Strictly speaking, only one parameter is changed at a time in a sensitivity analysis). In the statistical sensitivity analysis, sensitivity varies continuously because the base of precipitation input varies continuously. To illustrate, consider a "sensitivity analysis" of plot response to an alternate management practice (e.g. conservation tillage) that involves changing three parameters from their base values (those used for conventional tillage). Base precipitation input to the two treatments is identical for all events, but different from event to event, while the alterations in the three parameters from their base values remains constant. Next, the variability in individual annual plot response caused by precipitation is blocked by computing the difference in each annual value from the two treatments. Then the sample of differences is used to test the hypothesis that the two treatment effects on plot response are equal. That is, the differences are not significantly different from zero; or, to maintain the analogy to sensitivity analysis, sensitivity is not different from some percentage.

As indicated, precipitation is not the only source of variability in field observations other than the treatment effects being investigated. Soil structure, fertility, microbiology, moisture and temperature, are a few other factors that have uncontrolled temporal and spatial variance in the field before treatments are randomly assigned to plots. If there were no initial variability in the plots (perfectly homogeneous), an unrealistic ideal achievable only in the deterministic model, it would be easier to conclude that a change in management causes a significant reduction (or increase) in contamination potential. Variability due to uncontrolled factors other than that caused by rainfall, which is blocked, would tend to mask treatment effects. And, the more factors there are varying in time and space initially, the more difficult it becomes to detect landuse treatment effects. Since, in the model, there was no error variance in soil parameters, model output will often yield to conclusions of significant treatment effects when perhaps none would be detected in analogous field observations. That is, in a model and a field experiment having an equivalent duration, hypothesis tests on means of water quality constituents over the duration of the experiment would be more powerful using model output than they would be using field observations.

The duration of the experiment is also an important consideration in hypothesis testing. A longer annual record, or equivalently, a larger sample size provides more power to the hypothesis test. That is, by using a larger sample size, it is easier to reject the null hypothesis that treatment effects are equal. In modeling, it is possible to run very long and comprehensive experiments using stochastically generated precipitation as input. Estimates of simulated population means can be made very precise, and differences in treatment means can be made statistically significant no matter how small the differences are.

This modeling study considered several 2-year crop rotations and one 4-year rotation. For legitimate statistical tests, the systematic bias in predictions that occured over the duration of the experiment was removed. The systematic bias was a result of having a 2- or 4-year continuous sequence of alternating crops, tillage, and chemical applications. This is a problem because it creates an interaction effect between treatment (column effect) and year (row effect) within a crop rotation. That is, the effect of the treatment on a cell observation (an observation that occurs at the intersection of year and treatment) depends on which year of the rotation the observation occurs. Two-way statistical layouts are not valid when n = 1 observation per cell if row - column interaction is suspected.

A practical approach that removes systematic bias in predictions and accepts the averaging of the curve number and other parameters over a crop rotation is to average over the lowest common denominator of the lengths (years) of the rotations. For this study, 2 and 4-year rotations are used, so the averaging period is 4 years. Hence sample size (N) = 35/4 = 8 averages. In this study, the first three years (1951-1953) of output were discarded so that leaching patterns were established to some extent, and there was no effect of initial values. Treatments were carefully defined, and statistical inference on output averages were used to find treatment differences between all the two-year rotations and the four-year rotation. The blocking procedure to filter variance due to precipitation was appropriate because "quad-annual" average output between treatments was subject to identical precipitation input and strong dependence remained between output from different treatments. Within-sample variability was reduced as a consequence of taking quad-annual averages. This reduced variability would offset any loss of statistical power caused by a small sample size.

Many elements within the two-year rotations were identical, such as crops and timing of fertilizer application. Thus, related treatments could usually be isolated for statistical evaluation of treatment effects on potential water quality impacts. For example, alternative tillage practices prior to planting the same crop at the same time could be isolated to assess potentially significant effects on nitrate leaching. However, the presence of non-identical elements, which could not themselves be isolated as treatments, required precautions in drawing statistical conclusions. Significant treatment effects between rotations should not be reported without a qualitative consideration of other differing elements between each rotation that may contribute to statistical differences in model output. Statistical conclusions from the analysis of treatments - parts of management systems - must be coordinated with a good deal of qualitative support when whole systems are sought to minimize negative water quality impacts.

Assumptions and Nonparametric Statistics

Although much of the justification above pointed towards an appropriate statistical procedure, namely a two-way, balanced incomplete-block design, confirmation of underlying assumptions was necessary. The normality assumption dictated whether normal theory statistics would hold, or if non-parametric alternatives would be used.

Independence within samples was deemed a crucial requirement. The effect of serial correlation on inferences about means is often serious (Scheffe, 1959). Model output was a function of precipitation amounts, which are assumed to be random and independent on an annual basis. A finer level of discretization (e.g. daily values) may reveal serial correlation in precipitation and output variables. However, even on an annual basis, some output variables may exhibit serial correlation especially as a result of alternating tillage, nitrogen, and pesticide management practices which are repeated every other year in the two-year rotations and every fourth year in the four-year rotation. As previously indicated, quad-annual average output was used for each sample element. Thus, randomness and independence within samples was assumed. The assumption of random samples consisting of quad-annual elements was verified using a nonparametric test for randomness (runs test for randomness) on percolation, nitrate leaching, and atrazine leaching.

Normality of observations for sample sizes of 8 was difficult to confirm. However, based on visual inspection of histograms for sample sizes of 35, most, if not all, output variables were not normally distributed. However, the analysis of variance (ANOVA) procedure (test on means) has been proven to be robust to violations in the normality assumption (Scheffe, 1959). Nevertheless, to guard against extreme violations in the normality assumption, Friedman's distribution-free tests were used to determine if there were overall significant differences between at least two treatment effects. If significant differences were detected, paired sign tests were used to determine which treatment effects were different from one another. This procedure is analogous to Fisher's protected least significant difference procedure in which a two-way analysis of variance is followed by paired t-tests on all paired treatments, but only if the analysis of variance is significant at the pre-specified significance level (Foutz, 1990).

Homogeneity of variance between samples grouped according to related treatments was assumed. Equal variance is generally not a concern when an equal number of observations per treatment group is used. However, while all sample sizes in this study were 8, some inconsistent conclusions (in terms of multiple range tests) peculiar to Fisher's general procedure (which does not use multiple range tests) resulted when equal variance was not the case. The effect of unequal variance on statistical conclusions will be illustrated in the Results and Discussion section.

Friedman's test of the null hypothesis that treatment effects are equal does not require that observations be normally distributed. Observations under each treatment (within a row or block) are independent, but between treatment observations (columns) are not because of some unit of association (Gibbons, 1985). Each treatment observation within a row is replaced by a number (1, 2, 3, ..., k) which represents that treatments magnitude relative to the other observations in the same row. After ranking, the test statistic (S) is computed from the sum of squares of deviations between the expected column totals and actual column totals. Each expected column total is the same and equals the average column total; actual column totals are affected by treatment differences. The tail area of the probability distribution for S is delimited by the calculated test statistic, and must be less than the pre-specified significance level in order to reject the null hypothesis that treatment effects are equal.

If Friedman's overall test is significant, sign tests are performed on separate treatment pairs to find which treatment effects are different from each other. The probability of a given number of positive (or negative) signs in the sample of differences between treatments follows the binomial probability distribution. Hence, for a given sample size (N), the p-value is discrete for any K signs greater (less) than 0 - the expected difference between treatment observations if the null hypothesis were true. The p-value must be less than the pre-specified significance level in order to reject the null hypothesis.

RESULTS AND DISCUSSION

HYDROLOGY AND SEDIMENT YIELD

Runoff

The hydrologic budget over all nine tillage-cropping practices for the 35-year simulations showed that on the average evapotranspiration accounts for nearly 79% of precipitation, with percolation about 17% and runoff 4% of precipitation. The breakdown of runoff from specific crop rotations shows that rotations that used conventional tillage prior to planting corn and soybeans had higher runoff than rotations with conservation tillage practices. Table 6 shows statistically significant differences between predictions of 35-year average annual runoff from the nine (hydrologically different) rotations. A maximum 39% decrease in runoff was predicted if the 4-year conventional corn and full-season soybean rotations (12, 13, 14, and 19) were replaced with the 2-year rotations (8, 9, 10, and 18) of no-till corn and soybeans double-cropped with winter wheat followed by rye winter cover.

Sediment Yield

The largest significant difference in average sediment yield, 59%, was also found to occur between the two tillage-cropping practices described above that had the greatest difference in runoff. Rotations that used conventional tillage prior to planting corn and soybeans had higher erosion than rotations with conservation tillage practices. Highest erosion from conventional rotations was the result of a reduction in surface cover and higher runoff volumes. Table 7 shows the ranking, from greatest to least, of 32-year average annual erosion predictions for each of the nine rotations, and significant differences are indicated.

All values are below the soil loss tolerance, which for Suffolk sandy loam in Richmond County is 6.7 Mg/ha/yr (USDA-SCS, 1983).

Percolation

Average predicted annual percolation was highest under the no-till corn rotation 2. Percolation was highest under rotation 2 because runoff was reduced due to high residue cover remaining from double-cropped soybeans in which no-till corn was planted, and because evapotranspiration demand was reduced by the absence of a winter-cover crop after soybeans. The combination of these factors resulted in relatively more water being available for percolation. When winter cover crops following double-cropped soybeans were used (rotations 8, 11, 15), higher evapotranspiration reduced long-term percolation. With the exception of rotation 2 which had significantly greater percolation, percolation for the other eight rotations varied between 17.2 and 19.3 cm/yr, a maximum difference of 12%. Differences between the 28 other pairings excluding rotation 2 were generally not significant. Table 8 shows the ranking of 35-year average annual percolation volumes under each rotation and the significance levels for each.

Table 6. Thirty-two Year Average Annual Runoff Predictions*

ROTATION		RUNOFF#
Description	Numbers	(cm)
CT-corn/NT soybeans/CT soybeans/NT soybeans	12,13,14,19	5.9 a
CT-corn/NT-soybeans	1,4,6,7,17	5.4 b
Disk corn, cult. 3x/NT beans, cult. 3x - rye & clover WC	16	4.9 c
Disk-corn/NT-soybeans	5	4.8 c
NT-corn, cult. 3x/NT-soybeans, cult 3x - rye WC	11	4.5 d
Chisel-corn/NT-soybeans	3	4.4 d
Disk corn/NT beans - rye & clover WC	15	4.0 e
NT-corn/Disk-soybeans	2	4.0 e
NT-corn/NT-soybeans - rye WC	8,9,10,18	3.6 f

* 32-year average precipitation = 109 cm

\# Means with same letter are not significantly different at the .05 level. Sign tests on samples of quad-annual averages

Table 7. Thirty-two Year Average Annual Erosion Predictions

ROTATION		SEDIMENT YIELD*
Description	Numbers	(Mg/ha)
CT-corn/NT soybeans/CT soybeans/NT soybeans	12,13,14,19	6.3 a
CT-corn/NT-soybeans	1,4,6,7,17	5.5 b
Disk-corn/NT-soybeans	5	4.6 c
Chisel-corn/NT-soybeans	3	4.3 d
NT-corn/Disk-soybeans	2	3.5 e
NT-corn, cult. 3x/NT-soybeans, cult 3x - rye WC	11	3.2 e
Disk corn, cult. 3x/NT beans, cult. 3x - rye & clover WC	16	3.0 e,f
Disk corn/NT beans - rye & clover WC	15	2.7 g
NT-corn/NT-soybeans - rye WC	8,9,10,18	2.6 f,g

* Means with same letter are not significantly different at the .05 level sign tests. Sign tests on samples of quad-annual averages

Table 8. Thirty-two Year Average Annual Percolation Predictions*

ROTATION		PERCOLATION#
Description	Numbers	(cm)
NT-corn/Disk-soybeans	2	22.5 a
Chisel-corn/NT-soybeans	3	19.3 b,d
NT-corn/NT-soybeans - rye WC	8,9,10,18	19.1 c
Disk-corn/NT-soybeans	5	18.9 b,c,e
Disk corn/NT beans - rye & clover WC	15	18.7 d,e,f
CT-corn/NT-soybeans	1,4,6,7,17	18.4 f,g
NT-corn, cult. 3x/NT-soybeans, cult 3x - rye WC	11	18.3 g
Disk corn, cult. 3x/NT beans, cult. 3x - rye & clover WC	16	17.9 h
CT-corn/NT soybeans/CT soybeans/NT soybeans	12,13,14,19	17.2 f,g,h

* 32-year average precipitation = 109 cm

\# Means with same letter are not significantly different at the .05 level sign tests. Sign tests on samples of quad-annual averages

Deviations in the equal variance assumption between treatment samples explains some otherwise unexpected conclusions of significant (or non-significant) differences between treatment effects on predicted percolation means. Variance has an indirect effect on the power of sign tests relative to its normal-theory counterpart, the t-test, which uses variance directly in the calculation of the test statistic. However, statistical power and conclusions from both tests are affected by variance in a similar manner. For example, the ranking of percolation averages from greatest to least in Table 8 indicates that a mean value of 18.3 cm/yr under rotation 11 is significantly greater than 17.9 cm/yr under rotation 16, but not significantly greater than 17.2 cm/yr under rotation 12. The sample of eight differences between rotations 11 and 16 had lower variance than the difference sample between rotations 11 and 12.

Other important observations were made concerning Friedman's test for overall significance and subsequent sign tests for significantly different treatment effects on runoff, erosion, and percolation between each of the paired tillage-cropping practices (36 pairings). For a sample size of eight, sign tests will only yield conclusions of significant difference at the .05 level if the signs of differences between sample elements are all positive (or all negative), and no differences are exactly zero. That is, a single deviation from otherwise positive (negative) values in differences between sample elements would cause failure to reject the null hypothesis: tillage-cropping treatments cause equal response. Smaller sample size reduces the power of hypothesis tests. However, the procedure that removed systematic bias and resulted in sample sizes of eight, also greatly reduced sample variance so that the sign of all elements in the difference samples became consistently less (or greater) than zero unless all differences in each sample were quite close to zero.

NUTRIENT MANAGEMENT

Nitrate loading to groundwater is a function of the volume of water that percolates through the root zone and the nitrate present in the root zone. Nitrate in the root zone is increased by N application rates and mineralization of organic nitrogen, and decreased by plant uptake, denitrification, and leaching and runoff losses. An average annual nitrogen balance of input minus output approximately equals zero for these simulated factors, with change in storage of nitrate in the root zone making up the difference. The 35-year average annual values for CREAMS nitrogen simulations for the four nutrient management scenarios and nine tillage practices are given in Table 9.

Tillage-Cropping Practices

Rotation 2, which has relatively high N application rates and a higher long-term average percolation volume than any of the other tillage-cropping practices, had the highest nitrate leaching of all rotations for each of the four nutrient management scenarios. However, when the variability of application rates were taken into account by representing leaching as percentages of crop-available N inputs, differences between all rotations became less pronounced (Table 9). Any trend in leaching or other losses between (and within) rotations as effected by tillage-cropping practices could be expressed by using their percentages of total N input.

Table 9. CREAMS Nutrient Simulation Results (32-year average annual values)

Rotation #	Scenario #	---- N APPLIED ---- Poultry Litter org./inorg.	Comm. N	Mineralized N	Total N Input[a]	NO_3 in Runoff	Uptake	Denitrification	Leach	Leach (% of Input)
		(kg/ha/yr)								%
1	1		106.1	56.7	171.5	0.72	137.6	6.8	27.5	16.0
1	2	63.8/ 42.5		120.5	172.1	0.56	126.4	8.2	37.3	21.7
1	3		118.2	56.7	183.6	0.74	140.6	8.6	35.0	19.1
1	4	70.9/ 47.3		127.7	183.6	0.57	133.6	9.2	41.1	22.4
2	1		138.2	56.7	203.6	0.48	149.7	10.6	44.8	22.0
2	2	83.0/ 55.4		139.8	203.9	0.40	140.3	11.5	53.0	26.0
2	3		150.2	56.7	215.6	0.51	146.6	13.1	58.1	26.9
2	4	90.2/ 60.1		147.0	215.9	0.40	146.1	12.7	58.1	26.9
3	1		87.2	56.7	152.6	0.43	123.0	5.4	24.1	15.8
3	2	52.2/ 34.9		109.0	152.6	0.42	112.8	7.0	33.1	21.7
3	3		91.2	56.3	156.2	0.43	121.6	6.6	28.5	18.2
3	4	54.7/ 36.7		111.5	156.9	0.42	115.9	7.3	33.7	21.5
4	1		104.6	56.7	170.0	0.73	136.7	6.8	26.9	15.8
4	3		118.2	56.7	183.6	0.75	141.5	8.5	34.1	18.6
5	2	62.4/ 41.6		119.1	169.4	0.50	124.6	8.1	37.0	21.8
5	4	69.6/ 46.4		115.9	171.0	0.50	124.6	8.5	38.2	22.3
8	1		113.2	67.6	189.5	0.37	144.4	7.9	38.8	20.5
8	2	67.9/ 45.3		135.1	189.1	0.34	140.4	8.4	40.8	21.6
8	3		118.2	67.6	194.5	0.37	143.9	8.7	43.3	22.2
8	4	70.9/ 47.3		138.2	194.2	0.34	142.0	8.9	42.2	21.7
11	2	68.0/ 45.3		135.2	189.2	0.44	141.2	8.3	40.3	21.3
12	1		72.6	51.2	132.5	0.69	102.7	4.8	19.4	14.6
12	2	43.6/ 29.0		94.7	132.4	0.59	101.4	5.7	25.3	19.1
12	3		84.4	51.2	144.3	0.71	114.5	5.7	23.6	16.4
12	4	50.6/ 33.8		88.4	130.9	0.59	99.2	5.8	25.8	19.7
15	1		93.1	90.0	191.8	0.41	149.7	7.2	35.8	18.7
15	2	55.7/ 37.2		145.4	191.3	0.38	143.6	8.2	40.1	21.0
15	3		118.2	90.0	216.9	0.44	155.4	10.9	52.0	24.0
15	4	70.9/ 47.3		160.6	216.6	0.40	154.8	10.8	52.1	24.0
16	2	55.8/ 37.2		145.5	191.4	0.48	144.3	8.1	39.4	20.6
16	4	70.9/ 47.3		160.5	216.5	0.51	155.5	10.8	51.3	23.7

[a] Inorganic/Commercial N + Mineralized N + Avg. nitrate from precipitation
Average nitrate from precipitation = 8.8 kg/ha/yr

Variable application rates and methods were considered to be properties of the different tillage-cropping practices. However, separate statistical analyses were performed for each N management scenario to isolate as much as practical tillage-cropping treatments to be compared for significantly different effects on nitrate leaching. Thus, Friedman's test and subsequent sign tests were performed on the nine tillage-cropping practices four times, once for each of the four different nutrient management scenarios. Significantly different effects of rotations with different tillage-cropping practices on nitrate leaching are shown in Table 10. Some tillage-cropping practices were not used with all four nutrient management scenarios.

The significantly highest percolation from rotation 2 suggests that nitrate leaching would be highest from rotation 2 as well if N application rates were equal for all rotations. In fact, nitrate leaching from rotation 2 was higher than from any other rotation. However, this was perhaps mostly a result of the relatively high N application rates on rotation 2. Leaching from rotation 2 was not significantly greater than from rotations 8 (scenario 1) and 15 (scenario 3). Scenarios 1 and 3 are split-applied commercial N scenarios that, respectively, account for N in the previous crop residue, and ignore crop residue N. Apparently, in scenario 1, crop uptake of N in rotation 2 was still sufficient to remove some nitrogen that was applied in excess of the amount applied to rotation 8. Greater denitrification also occurred in rotation 2 in response to higher N application rates. In scenario 3, leaching increased across all rotations with respect to scenario 1, but the relative difference between rotation 2 and 15 in particular became less. N contributions of crop residues in rotation 15 were high as a result of using an additional rye and clover winter cover crop. Although N application amounts were much less in rotation 15 compared to rotation 2, average total N input was the same when the N contributions of the crop residues were ignored (scenario 3). Remaining comparisons other than the equivalent total N input showed that crop uptake was 8 kg/ha/yr greater in rotation 15, and denitrification was 2 kg/ha/yr less. The 6 kg/ha/yr difference reflects the 6 kg/ha/yr greater leaching from rotation 2.

Table 10. Statistical Results of Tillage-Cropping Effects on 32-year, Average Annual Nitrate Leaching

Rotation #	NO3 (kg/ha/yr) Leached*
Scenario 1: Commercial N application accounting for residue N	
2	44.8 a
8	38.8 a
15	35.8 b
1	27.5 c
4	26.9 c
3	24.1 d
12	19.4 e
Scenario 2: Poultry Litter N application accounting for residue N	
2	53.0 a
8	40.8 b
11	40.3 c,d
15	40.1 c,d
16	39.4 e
1	37.3 b,c,e
5	37.0 b,d,e
3	33.1 f
12	25.3 g
Scenario 3: Commercial N application ignoring residue N	
2	58.1 a
15	52.0 a,b
8	43.3 c
1	35.0 b,c,d
4	34.1 d
3	28.5 e
12	23.6 e
Scenario 4: Poultry Litter N application ignoring residue N	
2	58.1 a
15	52.1 b
16	51.3 c
8	42.2 d,e
1	41.1 e
5	38.2 d
3	33.7 d
12	25.8 f

*Means with the same letter within each scenario are not significantly different at the .05 level

As a result of lower application rates, rotations 3 and 12 had significantly less nitrate leaching than most of the other rotations for each nutrient management scenario. Percolation for rotation 12 was not significantly less than several of the other rotations, and for rotation 3, percolation was actually significantly greater than many others (Table 8). Thus, different N application rates between rotations with the same N management scenario apparently had the greater effect on nitrate leaching than different percolation caused by different tillage-cropping practices between rotations.

Poultry Litter versus Commercial Fertilizer

To test for significantly different leaching response due to poultry litter versus commercial fertilizer applications, individual sign tests were performed on each N-scenario 1 and 2, and scenario 3 and 4 pairs within each rotation in which other conditions were equal. Because each test consisted of only two treatments, Friedman's test was not needed. Results of the sign tests are presented in Table 11.

Table 11. Sign Test of Median = 0.00 versus not equal 0.00 to Test for Significant Leaching Differences under Poultry Litter versus Commercial Fertilizer

Paired N Scenario	Rot.#	N	BELOW	EQUAL	ABOVE	P-VALUE	MEDIAN
1-2	1	8	8	0	0	0.0078	-10.55
1-2	2	8	8	0	0	0.0078	-7.937
1-2	3	8	8	0	0	0.0078	-9.587
1-2	8	8	7	0	1	0.0703	-1.625
1-2	12	8	8	0	0	0.0078	-6.450
1-2	15	8	8	0	0	0.0078	-4.200
3-4	1	8	8	0	0	0.0078	-6.012
3-4	2	8	4	0	4	1.0000	-0.6625
3-4	3	8	8	0	0	0.0078	-5.837
3-4	8	8	4	0	4	1.0000	0.1750
3-4	12	8	6	0	2	0.2891	-2.412
3-4	15	8	3	0	5	0.7266	0.3750

Table 11 shows that leaching was significantly greater at the .05 level from poultry litter scenario 2 than commercial nitrogen scenario 1 on five out of the six rotations on which the two scenarios were used. Figure 1 depicts within-rotation differences as well as differences in nitrate leaching between six of the nine rotations. Nitrate leaching was 37% greater when poultry litter was used instead of commercial nitrogen on rotation 3. Differences in losses by denitrification and nitrate in runoff between scenarios in a given rotation (Table 9) were not considered large enough to be factors in the statistical conclusions. However, the variability in nitrogen uptake was a major factor in determining the leaching differences of poultry litter versus commercial fertilizer because of the magnitudes of uptake involved.

All nitrogen from poultry litter was applied once prior to planting corn and wheat. Commercial N was split-applied, with the second application being higher (Appendix A). Lower uptake of nitrogen for all scenario 2 versus scenario 1 comparisons for each tillage-cropping practice (Table 9) indicates that N from poultry litter was not available for crop uptake at times when the crops needed it most. The inorganic N portion of poultry litter, which was supplied in greater amounts than the first application of 2-way split commercial nitrogen, was therefore susceptible to leaching before crop demand resulted in significant uptake.

Only the mineralizable portion of organic N from poultry litter and crop residue was input to CREAMS via the POTM parameter. There is no accounting for the non-mineralizable portion of organic N. Thus, on a long term basis, there is a direct balance between the POTM input and the mineralized N (Table 9). However, since mineralization is simulated as a function of temperature and moisture, a significant portion of N mineralization is not concurrent with crop N demand. Thus, mineralized organic-N from poultry litter may further increase the availability of N in the soil for loss via leaching.

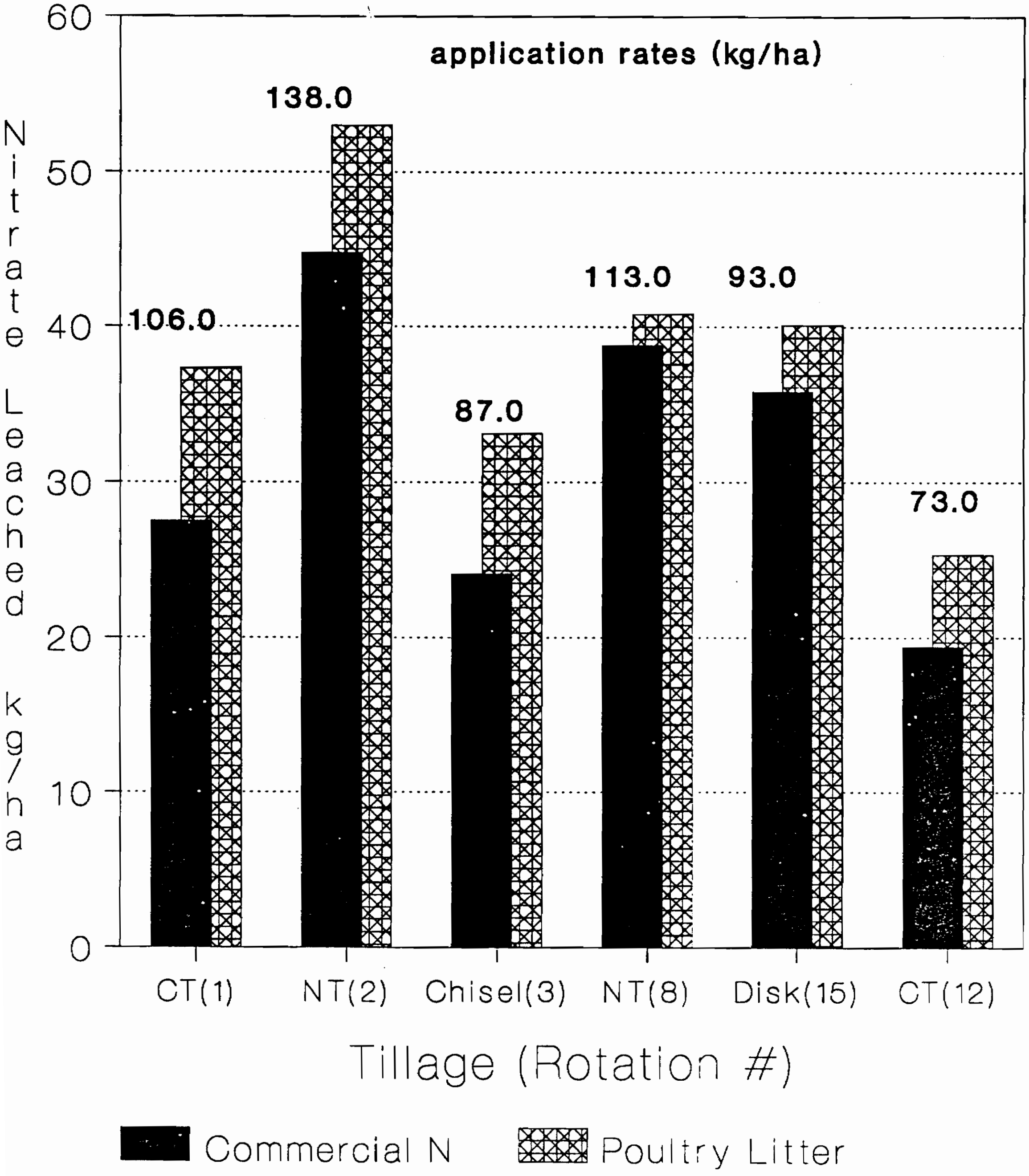

Figure 1. Nitrate Leached from Six Rotations Having Different Tillage Practices and Commercial N or N from Poultry Litter. ***Include*** **N from Crop Residue. (All values are 32-year Averages)**

The effect of using poultry litter versus commercial fertilizer on nitrate leaching was less pronounced when comparing scenarios 3 and 4, in which N application rates were increased because the N contribution of the previous crop residues were ignored. Figure 2 shows these scenario comparisons for the 6 rotations on which they were used. A lower rate of significance (two out of six) occured between the scenario 3 and 4 pairs (Table 11). A maximum 18% greater leaching occurred when poultry litter (scenario 4) was used instead of commercial nitrogen (scenario 3); however, 3 of the 6 scenario 3 - scenario 4 comparisons had slightly less nitrate leaching from poultry litter applications.

Increasing commercial N caused a greater increase in nitrate leaching than did increasing poultry litter N applications by the same amount on each crop rotation. Changes in plant uptake of scenario 3 compared to scenario 1 (commercial N) relative to scenario 4 compared to scenario 2 (N from poultry litter), indicate that most commercial N applications in scenario 3 are in excess of crop uptake potentials. This excess nitrate in the root zone contributes to leaching that is similar to leaching resulting from excessive and poorly timed poultry litter-N applications.

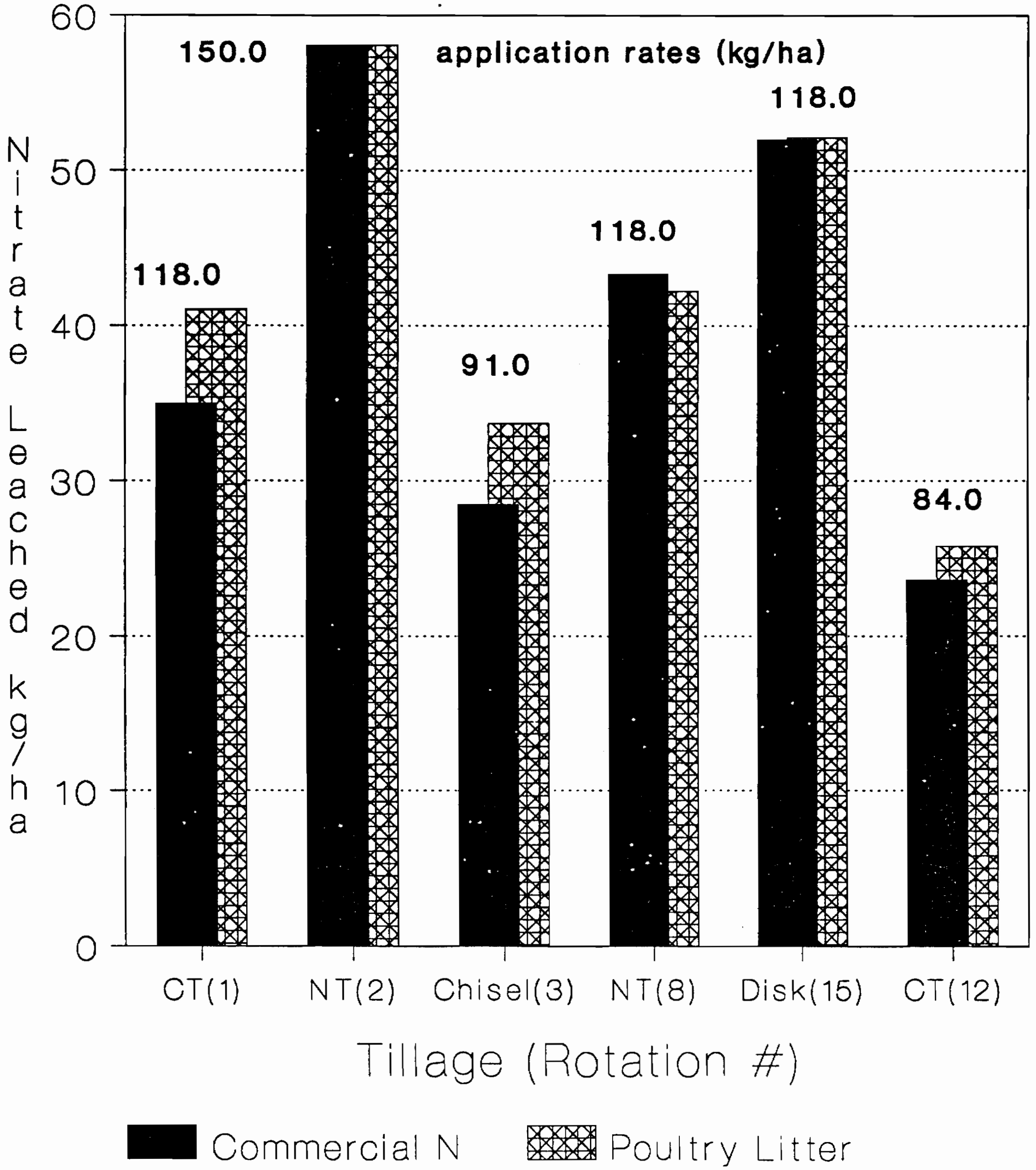

Figure 2. Nitrate Leached from Six Rotations Having Different Tillage Practices and Commercial N or N from Poultry Litter. *Ignore* N from Crop Residue. (All values are 32-year Averages)

Split Nitrogen Applications

The effect of a 3-way split versus a 2-way split application of commercial N on average predicted nitrate leaching was evaluated by comparing leaching for rotations 1 and 4 which have identical tillage-cropping practices and total nitrogen application amounts. Results in Table 9 show minor, 1.9% (scenario 1) and 2.4% (scenario 3), nonsignificant decreases in nitrate leaching if a 3-way split were used instead of a 2-way split commercial N application. The 3-way split application was used in only the wheat year of the 2-year rotation. N applications to corn and tillage practices were identical on rotation 1 and 4. Hence, differences in crop uptake, the remaining source of variability in nitrate leaching, were not apparent on a long-term average basis between rotations 1 and 4 for both scenarios.

The non-significant differences in mean nitrate leaching between rotations 1 and 4 were found by one-sided sign tests. While all prior tests have been two-sided (p-value for rejection < .025), this test was one-sided (p-value for rejection < .05) because the alternative hypothesis was that a 3-way split N application would *reduce* leaching significantly relative to the 2-way split application.

Application Rates

One-sided, paired sign tests were used to test the null hypothesis that high application rates that ignore the N-contribution of the previous crop residue would not result in greater leaching relative to lower N application rates that account for the residue contribution. Separate, within-rotation comparisons were made between scenarios 1 and 3 and between scenarios 2 and 4. The results are presented in Table 12. Four-fifths of the comparisons show that increasing N application rates caused a significant increase in nitrate leaching. The three scenarios that did not have significantly greater leaching were cases in which poultry litter applications were increased. These increases in total N were by an average 5 kg/ha/yr in rotation 5, and by 12 kg/ha/yr for both rotations 8 and 12.

Table 12. Sign Test of Median = 0.00 versus not equal 0.00 to Test for Significant Leaching Differences under "High" versus "Low" N Application Rates

Paired N Scenario	Rot.#	N	BELOW	EQUAL	ABOVE	P-VALUE	MEDIAN
1-3	1	8	8	0	0	0.0078	-7.625
1-3	2	8	8	0	0	0.0078	-12.54
1-3	3	8	8	0	0	0.0078	-4.375
1-3	4	8	8	0	0	0.0078	-7.912
1-3	8	8	8	0	0	0.0078	-4.462
1-3	12	8	8	0	0	0.0078	-4.062
1-3	15	8	8	0	0	0.0078	-14.98
2-4	1	8	8	0	0	0.0078	-3.550
2-4	2	8	8	0	0	0.0078	-5.225
2-4	3	8	8	0	0	0.0078	-0.5750
2-4	5	8	6	0	2	0.2891	-3.200
2-4	8	8	7	0	1	0.0703	-2.425
2-4	12	8	6	1	1	0.1250	-0.5500
2-4	15	8	8	0	0	0.0078	-13.01
2-4	16	8	8	0	0	0.0078	-12.90

The tests in Table 12 are exclusive from each other, so equal variance between each sample in any pairing was not required. However, a noteworthy result with respect to sample variances occured in paired scenario 2-4 of rotation 3. Average annual leaching for these were 32.2 and 32.9 kg/ha (Table 9), which was found by the sign test to be significantly different. The variance in the sample of eight differences was very low, which enabled all differences between the paired sample elements to be slightly less than zero, as evinced by the low median. Therefore, the sign test had relatively high power in this case, as it did in many other cases.

A 12% increase (12 kg/ha/yr) in added commercial N from scenario 1 to scenario 3 caused a significant 27% increase in leaching from both rotation 1 and 4. Similar comparisons for each of the other rotations can be made by using Table 9. Rotation 15 had the greatest increase in nitrogen applications of scenarios 3 and 4 over scenarios 1 and 2 (27% or 25 kg/ha/yr), and also the greatest increases in nitrate leaching of 45% under commercial N, and 30% under poultry litter. In rotation 12, average yearly commercial and poultry litter N applications were equivalently increased by 16% (12 kg/ha/yr) from scenarios 1 and 2 to scenarios 3 and 4, but leaching increases were only 22% and 2.0% under commercial and poultry litter N applications, respectively. The basic reason for the relatively small increase in nitrate leaching is that rotation 12 was a 4 year rotation and nitrogen was applied in only 2 (scenario 1 and 2) or 3 (scenario 3 and 4) of those years. Thus, greater increases in leaching in years of the 27% greater N applications is disguised by long-term averages that include years of zero nitrogen applications and only small increases in leaching. These comparisons and the statistical conclusions in Table 12, lend support to the conclusion that nitrate leaching is highly affected by N application rates, or to be more precise, total N inputs.

The effect of high versus low application rates in terms of total N input can be further investigated by between-rotation comparisons in Figures 1 and 2. Nitrate leaching between rotations 8 and 15 is especially interesting. When nitrogen was applied to account for the N contribution of previous crop residues (Figure 1), total N input between the two rotations was very nearly equal (Table 9). The resulting leaching was slightly less from rotation 15 compared to rotation 8. Yet, table 10 shows that rotation 8 had significantly less leaching than rotation 15 for scenarios 1 and 2. When nitrogen applications ignored the contributions of crop residues (Figure 2), total N input on rotation 15 became an average 22 kg/ha/yr greater than on rotation 8. This value reflects the additional mineralized organic N provided by clover which was not a part of the winter cover crop in rotation 8. As a result, leaching from rotation 15 now became significantly greater than rotation 8 for both scenarios 3 and 4. Thus, different total N inputs that include application rates and mineralization of organic N strongly affect nitrate leaching.

PESTICIDE MANAGEMENT

Unlike simulated nitrogen dynamics from which a clear balance occured between inputs and outputs, the GLEAMS simulation involves factors that account for the non-conservative nature of pesticides. The real magnitude and processes of pesticide decay (microbiological degradation, photolysis, hydrolysis, volatilization, etc.) are assumed to be adequately represented by foliar and soil half-life parameters used in the model. The organic-carbon partition coefficient largely determines the relative partitioning of pesticides into runoff, percolation, and sediment-bound losses. In the field, many interactions between tillage-cropping practices, N management scenarios, and chemical properties would occur to impact pesticide losses. In the simulations reported here, chemical properties such as the adsorption coefficient, and factors that affect them, such as organic matter in the soil, were homogeneous for each chemical on all rotations. Therefore, the analysis was simplified to consider only the effects of tillage-cropping practices with different hydrology, and the effects of pesticide application rates and methods on pesticide losses. The effect of different pesticide properties on losses was also evaluated from the partitioning of individual pesticides and pesticides with different properties substituted for others on rotations with the same hydrology.

Tables 13-15 show predicted losses of pesticides for each of the rotations on which they were applied. Pesticides with zero losses with runoff, sediment, or percolation have been omitted from the respective tables.

Table 13. Predicted Dissolved Pesticide Losses with Runoff (35-year average annual results)

ROTATION #	Atrazine	Metolachlor	Linuron	Gramoxone	Fenvalerate	Fluazifop-P	Linuron(Lorox)	2,4-D	Glyphosate	Alachlor	Trifluralin	Acifluorfen	Cyanazine
	(g/ha/yr)												
1	0.374	0.649	0.394	3.568	0.042	0.409	-	-	-	-	-	-	-
2	0.298	0.438	-	5.295	0.030	-	0.920	0.001	1.490	-	-	0.109	-
3	0.208	-	-	1.012	-	0.321	-	-	-	-	-	-	-
4	0.374	0.649	0.394	3.568	0.042	0.409	-	-	-	-	-	-	-
6	-	0.601	0.394	3.568	0.042	0.409	-	0.097	-	-	-	-	0.131
7	0.374	-	0.394	3.568	0.042	0.409	-	-	-	0.911	-	-	-
17	0.374	0.649	0.394	-	0.042	0.409	-	-	2.869	-	-	-	-
8	0.210	0.657	-	2.555	0.026	0.259	0.687	-	-	-	-	0.081	-
9	-	0.657	-	2.555	0.026	0.259	0.687	0.009	-	-	-	0.081	0.200
10	0.210	-	-	2.555	0.026	0.259	0.687	-	-	0.478	-	0.081	-
18	0.210	0.560	-	-	0.026	0.259	0.687	-	1.321	-	-	0.081	-
12	0.296	1.264	0.010	3.861	0.050	0.459	1.316	-	1.257	-	3.334	0.250	-
13	-	1.264	0.010	3.861	0.046	0.459	1.316	0.041	1.257	-	3.334	0.251	0.103
14	0.296	-	0.010	3.861	0.046	0.459	1.316	-	1.257	1.160	3.334	0.250	-
19	0.296	0.837	0.010	-	0.046	0.459	1.316	-	3.373	-	3.334	0.250	-
15	0.191	0.508	-	2.818	0.030	0.294	0.796	-	-	-	-		0.102

Table 14. Predicted Sediment-bound Pesticide Losses (35-year average annual results)

ROTATION #	Atrazine	Metolachlor	Linuron	Gramoxone	Fenvalerate	Fluazifop-P	Linuron(Lorox)	2,4-D	Glyphosate	Alachlor	Trifluralin	Acifluorfen	Cyanazine
	(g/ha/yr)												
1	0.007	0.008	0.018	25.006	0.210	0.067	-	-	-	-	-	-	-
2	0.004	0.004	-	32.207	0.125	-	0.033	0.000	0.670	-	-	0.001	-
3	0.003	-	-	6.930	-	0.059	-	-	-	-	-	-	-
4	0.007	0.008	0.018	25.006	0.210	0.067	-	-	-	-	-	-	-
6	-	0.007	0.018	25.006	0.210	0.067	-	0.001	-	-	-	-	0.003
7	0.007	-	0.018	25.006	0.210	0.067	-	-	-	0.011	-	-	-
17	0.007	0.008	0.018	-	0.210	0.067	-	-	1.425	-	-	-	-
8	0.001	0.004	-	12.473	0.105	0.044	0.029	-	-	-	-	0.001	-
9	-	0.004	-	12.473	0.105	0.044	0.029	0.000	-	-	-	0.001	0.000
10	0.001	-	-	12.473	0.105	0.044	0.029	-	-	0.003	-	0.001	-
18	0.001	0.003	-	-	0.105	0.044	0.029	-	0.609	-	-	0.001	-
12	0.004	0.015	0.001	26.330	0.244	0.071	0.058	-	1.116	-	0.349	0.002	-
13	-	0.015	0.001	26.330	0.224	0.071	0.058	0.000	1.116	-	0.349	0.002	0.001
14	0.004	-	0.001	26.330	0.224	0.071	0.058	-	1.116	0.013	0.349	0.002	-
19	0.004	0.010	0.001	-	0.224	0.071	0.058	-	2.143	-	0.349	0.002	-
15	0.002	0.005	-	12.820	0.113	0.048	0.033	-	-	-	-	0.001	-

Table 15. Predicted Dissolved Pesticide Losses with Percolation (35-year average annual results)

ROTATION #	Atrazine	Metolachlor	Chlorimuron	DPXM-6316	Acifluorfen	2,4-D	Alachlor	Cyanazine	Dicamba
	(g/ha/yr)								
1	0.525	0.003	0.037	0.009	-	-	-	-	-
2	0.553	0.006	-	0.010	0.007	0.003	-	-	0.595
3	0.469	-	-	-	-	-	-	-	-
4	0.525	0.003	0.037	0.009	-	-	-	-	-
6	-	0.002	0.037	0.009	-	0.017	-	0.006	-
7	0.525	-	0.037	0.009	-	-	0.006	-	-
17	0.525	0.003	0.037	0.009	-	-	-	-	-
8	0.624	0.010	-	0.023	0.006	-	-	-	-
9	-	0.010	-	0.023	0.006	0.008	-	0.004	-
10	0.624	-	-	0.023	0.006	-	0.010	-	-
18	0.624	0.008	-	0.023	0.006	-	-	-	-
12	0.319	0.005	0.012	0.008	0.003	-	-	-	-
13	-	0.005	0.012	0.008	0.003	0.012	-	0.004	-
14	0.319	-	0.012	0.008	0.003	-	0.005	-	-
19	0.319	0.003	0.012	0.008	0.003	-	-	-	-
15	0.958	0.009	-	0.022	0.005	-	-	-	-

Tillage-Cropping Practices

Predicted losses were equivalent for rotations having identical pesticide applications and identical hydrology and erosion as determined by tillage-cropping practices. Groups consisting of rotations 1, 4, 6, 7, and 17; rotations 8, 9, 10, and 18; rotations 12, 13, 14, and 19; and the individual rotations 2, 3, and 15 had unique tillage-cropping practices that were compared for impacts on losses of selected pesticides.

Figure 3 shows atrazine losses as a function of tillage, application rates, and chemical properties. Atrazine was applied before planting corn. For all rotations, most of the total loss of atrazine was with percolation through the root zone, a smaller portion was with runoff, and a negligible portion was with sediment. This partitioning reflects low soil adsorption simulated for atrazine. Tillage immediately after applying atrazine and before planting corn was important in determining the magnitude of losses in the various pathways. Differences in the impacts of tillage and application factors on atrazine losses were investigated using Friedman's test and subsequent sign tests. Results are given in Table 16.

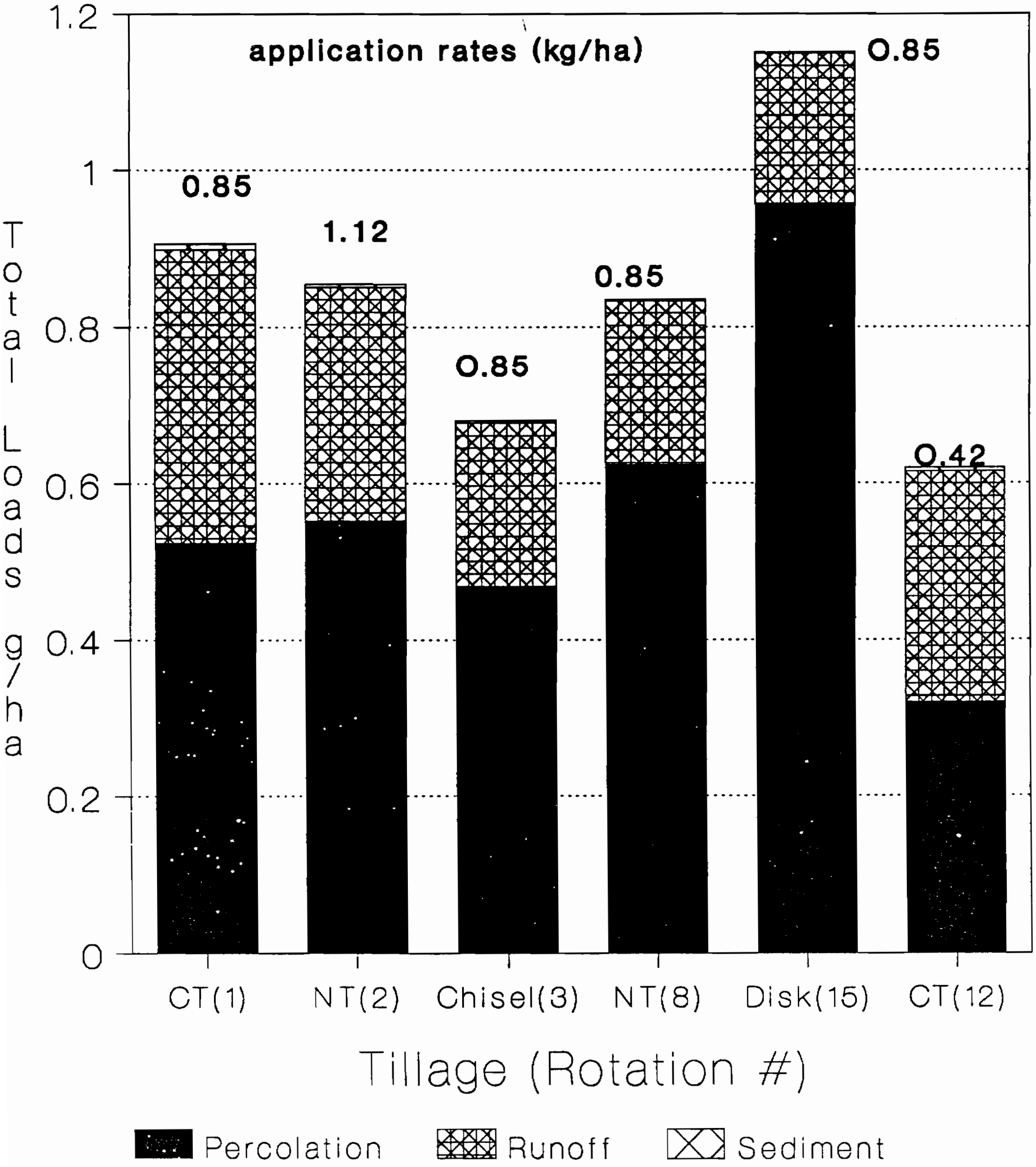

Figure 3. Thirty-five year Average Atrazine Loads with Percolation, Runoff, and Eroded Sediment from Six Rotations with Different Tillage Practices

Table 16. Statistical Results of Tillage-Cropping Effects on Atrazine Losses*

ROTATION #	LOSS WITH RUNOFF (g/ha)	LOSS WITH SEDIMENT (g/ha)	LOSS WITH PERCOLATION (g/ha)
1	0.374 a	0.007 a	0.525 b,c
2	0.298 a,b	0.004 a,b	0.553 b
3	0.208 a,b	0.003 b	0.469 c,d
8	0.210 a,b	0.001 c	0.624 b
12	0.296 a,b	0.004 a,b	0.319 d
15	0.191 b	0.002 c	0.958 a

* Means with the same letter within each column are not significantly different at the .05 level. Sign tests on samples of quad-annual averages

Disk-incorporation of atrazine (rotation 15) caused the highest leaching and total losses. Percolation under rotation 15 was not particularly high (Table 8), but runoff was among the lowest (Table 6). Evapotranspiration of infiltrating water served to upwardly redistribute atrazine applied 5 cm into the root zone by disking. However, no portion of atrazine was applied to the soil surface, thus no volatilization was predicted. Thus, the mass of atrazine in the root zone was maintained for losses via leaching, runoff, and degradation as a function of its moderately long soil half-life (60 days).

Rotation 1 (conventional tillage) had significantly higher runoff, and runoff losses of incorporated atrazine than rotation 15, but significantly less leaching and total losses of atrazine than rotation 15. On the basis of this comparison, it is possible to conclude that atrazine that is incorporated by disking or by some other means on rotations that also have relatively low runoff may be susceptible to high leaching loss. However, the long-term average atrazine losses used in comparisons were influenced most by hydrologic conditions immediately after application, because the mass of atrazine available for loss begins to dissipate immediately after application. Recall that average curve numbers were used over each rotation. In reality hydrologic characteristics of the disked field (rotation 15) may be quite similar to the conventional tilled field (rotation 1), and significant differences in atrazine losses may not occur. Furthermore, samples for comparison in this study were protected from extraneous variability that would occur in the field.

The highest percolation, and generally 32% higher atrazine application rates occured on no-till corn rotation 2. However, predicted leaching loss of atrazine was significantly greater from rotation 2 than from only two other rotations, one of which (rotation 12) had 62% less atrazine applied than rotation 2. On rotation 2, atrazine was surface applied to soil with a 40% residue cover prior to planting no-till corn. Therefore, a relatively large amount of atrazine on rotation 2 was lost by volatilization as simulated as a function of foliar half-life.

The conventional four-year rotation (12) had the lowest average leaching losses of atrazine, partly because runoff was highest under this rotation, but primarily because atrazine was applied at a rate of 1.7 kg/ha in only 1 of 4 years. In the other, 2-year rotations, atrazine was applied every other year, and there was not as much time for dissipation in the intervening year. Highest runoff in rotation 12 explains why surface runoff losses of atrazine were high for this rotation.

Figure 4 shows gramoxone losses as a function of tillage, application rates, and chemical properties. Gramoxone was generally applied to kill winter wheat prior to planting double-cropped, no-till soybeans, but rotation 2 had an additional application before planting no-till corn. The high adsorptivity of gramoxone makes it susceptible to loss with eroded sediment. Its long soil half-life indicates that gramoxone is not affected by microbiological degradation in the root zone. However, some initial surface decay after each application was simulated as a function of foliar half life, because for all rotations, gramoxone was applied to winter wheat residue and the soil surface. Averaging gramoxone losses over complete rotations for long-term comparisons between rotations was reasonable because its long soil half-life made losses susceptible to conditions at any time during a rotation. Significance tests were not performed on gramoxone losses, but the relationship of losses to erosion and runoff was quite clear.

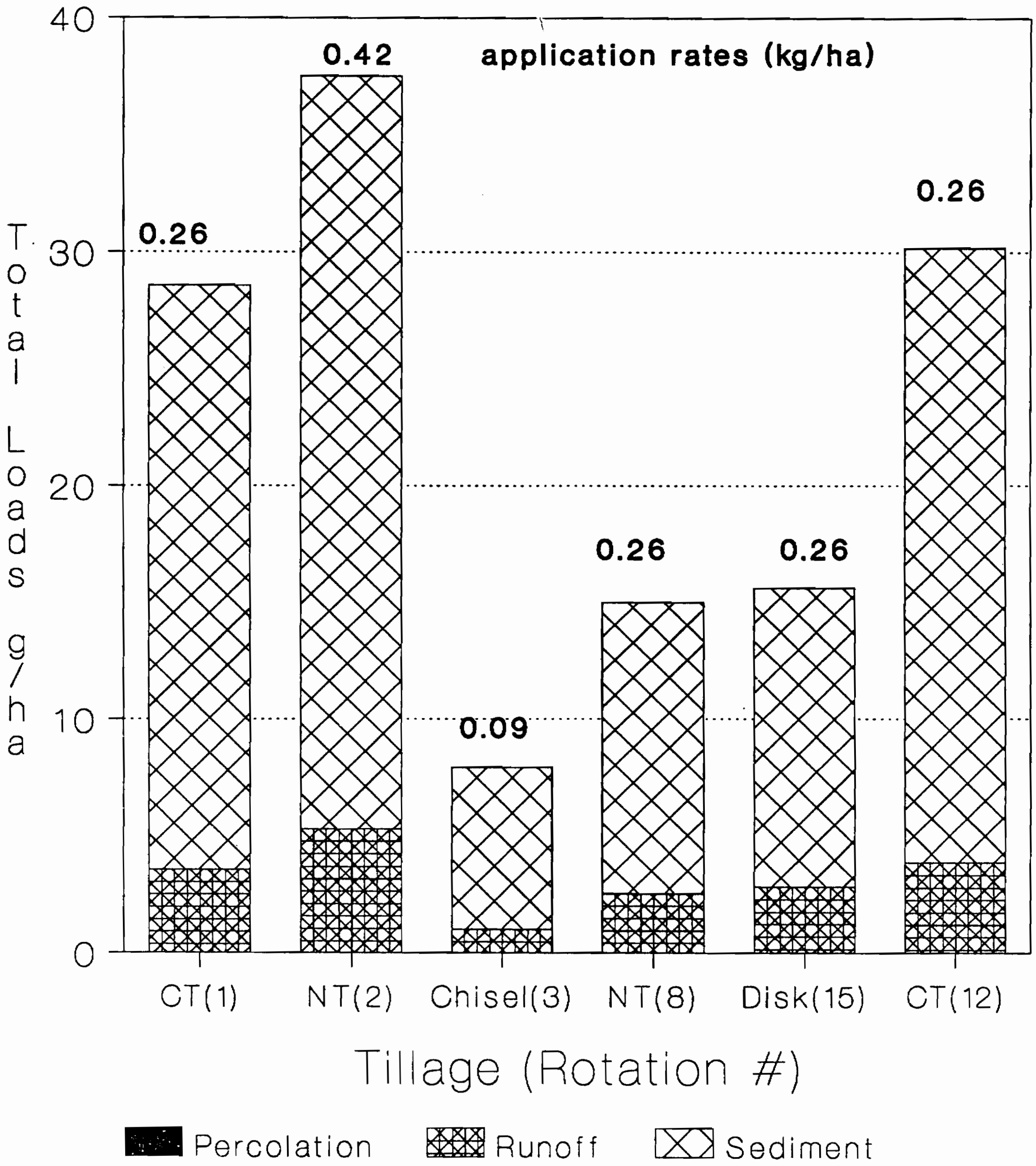

Figure 4. Thirty-five year Average Gramoxone Loads with Percolation, Runoff, and Eroded Sediment from Six Rotations with Different Tillage Practices

Rotations using gramoxone show 82-87% of total losses are with sediment, 13-18% are with runoff, and no losses occur via leaching. Practices that limit runoff and erosion will therefore have the greatest effect on reducing losses of this herbicide. For example, comparing rotation 8 (no-till corn and no-till double-cropped soybeans followed by rye winter cover) with rotation 1 (conventional till corn and no-till double-cropped soybeans), the 33% decrease in runoff and 53% decrease in sediment yield caused a 28% reduction of gramoxone with runoff and a 50% reduction in sediment-bound losses.

Apparently, variable application rates would greatly affect gramoxone losses. In rotation 3, the gramoxone application prior to double-cropped soybeans was 66% less than most other rotations (Figure 9). This reduction in amount was more than reflected by a 72% reduction in gramoxone losses with runoff and with sediment compared to rotation 1 (medium chemicals). Of course, this 72% reduction is exaggerated because the reduction in application amount interacts with the reduction in erosion. A more reasonable comparison using rotation 15, which had significantly less erosion and runoff than rotation 3 (Tables 7 and 6), showed (conservatively) that the 66% reduction in application amount reduced gramoxone losses with sediment by 46%, and losses with runoff by 64%.

Pesticide Substitution

The benefits of substituting pesticides having similar weed control characteristics but different chemical properties, such as solubility, half-life, and adsorptivity, were evaluated. 2,4-D and cyanazine was used as a substitute for atrazine on rotations 6, 9, and 13. Alachlor was a substitute for metolachlor on rotations 7, 10, and 14. Glyphosate was a substitute for paraquat on rotations 17, 18, 19.

From the simulation results, 2,4-D and cyanazine were lost more with runoff than with percolation for rotations 6, 9, and 13, while atrazine was lost more with percolation than with runoff. Greater solubilities of 2,4-D and cyanazine (Table 2) compared to atrazine explains their greater losses with runoff than with percolation. Percolation losses of atrazine were particularly high under conservation-tillage rotations on which atrazine was incorporated with corn planting. Therefore, the substitution of 2,4-D and cyanazine for atrazine on no-till rotations in particular might be beneficial from a groundwater quality perspective because 2,4-D and cyanazine were generally more susceptible to runoff loss than loss with percolation. Figure 5 displays the relative partitioning of 2,4-D and atrazine. An overall relative reduction in 2,4-D loading compared to atrazine is apparent under the no-till rotation (middle bars). Leaching losses of 2,4-D are low and runoff losses would be reduced by no-till (not shown). Furthermore, total loadings of 2,4-D and cyanazine by all routes are less than that of atrazine. However, to assess the relative advantages of this substitution for groundwater quality, differences in chemical toxicity would have to be considered along with results presented here.

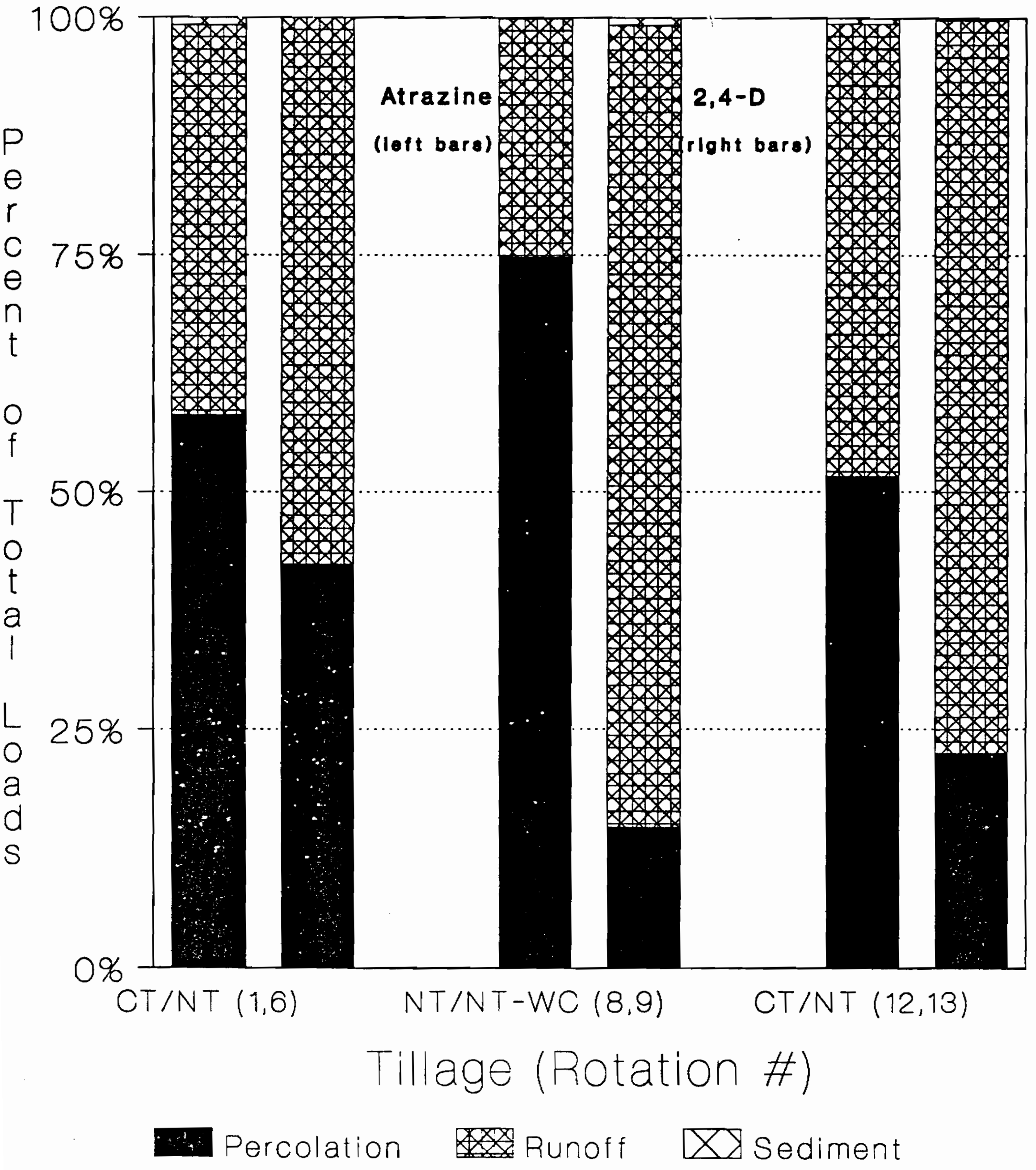

Figure 5. 2,4-D Substitution for Atrazine on Three Rotations with Different Tillage Practices. Percent of Total Loads by Percolation, Runoff, and Sediment are Based on 35-year Average Loads

Metolachlor had similar loss pathways and loads as its potential substitute, alachlor, with the dominant loss pathway being with runoff. But once again toxicity would also have to be considered to assess the environmental consequences of this substitution.

Glyphosate substitution for paraquat is shown in Figure 6. There is no apparent benefit of the substitution without consideration of toxicity, because both pesticides were lost via surface routes. Figure 6 shows that a higher portion of total glyphosate losses were with runoff in all rotations than with sediment. The opposite was true of gramoxone, but neither pesticide leaches. Rotations that reduce runoff and erosion would reduce glyphosate lost with runoff (54% for a no-till versus conventional till comparison) by a similar percentage as gramoxone lost with sediment (50% for the same tillage comparison).

Toxicity and economic factors notwithstanding, a pesticide management practice should substitute pesticides that have a low leaching potential for those that have a high leaching potential on rotations that are designed to minimize runoff and erosion.

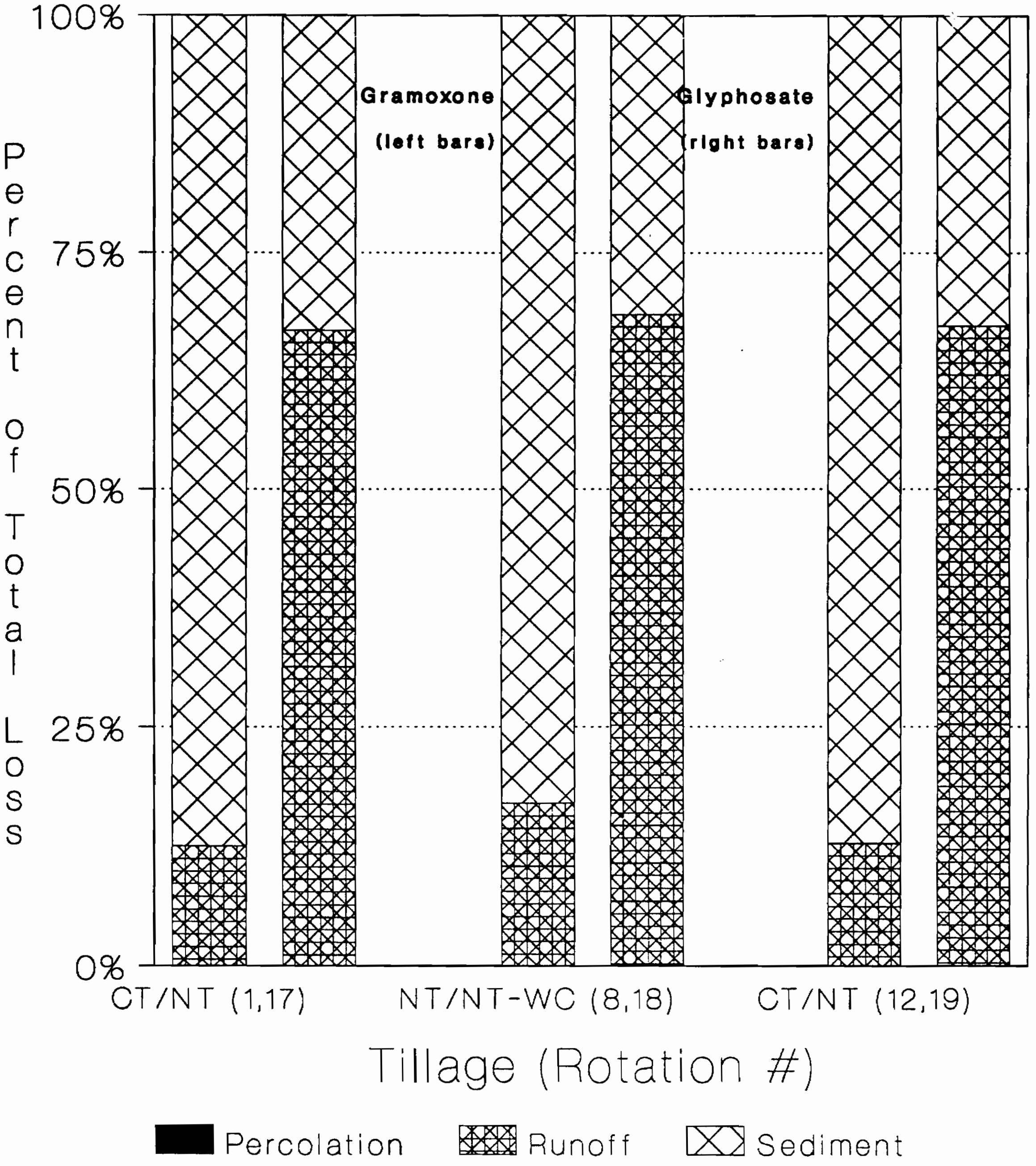

Figure 6. Glyphosate Substitution for Gramoxone on Three Rotations with Different Tillage Practices. Percent of Total Loads by Percolation, Runoff, and Sediment are Based on 35-year Average Loads

SUMMARY AND CONCLUSIONS

The CREAMS and GLEAMS NPS models were selected to simulate nitrate and pesticide pollution potential of alternative crop management systems in Richmond, County Virginia. Nine tillage-cropping practices served as the basis for evaluating 40 scenarios involving different rate and timing of nutrient and pesticide applications. For the analysis of scenario effects on hydrology, erosion, and chemical transport, two-way, nonparametric statistical procedures - Friedman's test and sign tests - were used. The assumption that annual variability in model output under each management system was representative of field data was deemed critical in justifying the statistical analysis. The unlikelihood of this assumption was realized, but in the investigation, limitations and strengths of using CREAMS and GLEAMS to accomplish the research objectives were discovered.

The simulations were viewed as inexpensive, tightly controlled experiments from which a reasonable assessment could be made of potential nonpoint source loading of agrichemicals from alternative management systems. Because of the required averaging of the curve number, saturated hydraulic conductivity, and other model-sensitive parameters over entire crop rotations, only average annual output encompassing all years of rotations was found to be appropriate for the evaluation of alternative systems.

The analysis of long-term average runoff and erosion predictions showed that reductions in runoff and sediment yield were greatest when no-till corn/double-cropped soybean systems were implemented, ideally with a winter cover crop after soybeans, instead of conventional-till corn / double-cropped soybean systems. When no-till systems with winter cover were implemented, predicted reductions in runoff range from 27 to 39%, and predicted reductions in sediment yield range from 37 to 59% compared to systems that include conventional-till corn.

Tillage practices that limit runoff and increase percolation were expected to have substantially higher nitrate leaching. Mass of nitrate leached was in fact highest under a no-till rotation which had the lowest long-term average runoff and the highest percolation. Leaching losses expressed as a percentage of total N input were more similar than actual losses across all rotations, albeit still reflective of leaching differences.

Relative leaching losses under poultry litter versus commercial nutrient management systems were dependent on the timing and quantity of nitrogen available from a crop need perspective. When recommended amounts of commercial N were applied in a 2-way split application, leaching losses were up to 36% less than if an equivalent amount of crop-available inorganic plus organic N from poultry litter was applied in a single pre-plant application. Differences in N leaching between commercial N and equivalently applied nitrogen from poultry litter were much less if commercial N was applied at rates that were in excess of crop needs.

Total crop-available N application rates, which include mineralized organic N from crop residues and poultry litter, had a greater effect on leaching than did different methods and timing of application. 3-way versus 2-way split N application, in addition to different tillage-cropping practices and poultry litter versus commercial N, did not impact leaching as much as high versus low application rates. Thus, "excess" nitrate in the crop root zone was the main cause of high nitrate leaching. This "excess" was found to result from poorly timed poultry litter applications or from high nitrogen application rates that ignored the N contribution of the previous crop residue.

Pesticide properties (adsorption, half-life) vary greatly between compounds. Relative losses in runoff, sediment, and percolation were dependent on these properties, and on the tillage-cropping practices by which pesticides were applied. Paraquat, which is highly adsorbed, may be most suitable to no-till fields from which erosion is greatly reduced. A 33%

reduction in runoff and a 53% reduction in sediment yield is predicted to cause a 28 and 50% reduction in paraquat lost with runoff and sediment, respectively, from conservation versus conventional rotations. Additional reductions of paraquat loss could be obtained by reducing application rates. A 66% reduction in use on a conservation tillage rotation compared to a conventional tillage rotation was predicted to reduce runoff and sediment-bound losses by 72%.

Pesticides with relatively low soil adsorptivity, such as atrazine or 2,4-D, applied to fields from which runoff is reduced may be a threat to groundwater. Volatilization losses of surface-applied atrazine may greatly offset the threat to groundwater as less is available for leaching. However, increased applications of atrazine to overcome volatilization losses and to maintain its effectiveness for weed control may have adverse effects on air quality and farm profitability. The benefits of using pesticides with different properties as substitutes for others could be assessed by combining the results of these simulations with information on the toxicity and cost of individual pesticides.

The general conclusions of this research are: 1) The nitrate contamination threat to groundwater can be minimized if nitrogen is applied in close accordance with crop needs; and 2) The fate and transport of pesticides can be controlled by accounting for interacting effects of application rates, chemical properties, and tillage-cropping practices.

REFERENCES

Addiscott, T.M., and R.J. Wagenet. 1985. Concepts of solute leaching in soils: A review of modeling approaches. J. Soil Sci. 36:411-424.

Beasley, D.B. and L.F. Huggins. 1982. ANSWERS-users manual, Rep. No. EPA-905/9-82-001. U.S. Environmental Protection Agency, Chicago, Ill. 53p.

Bevin, K. and P. Germann 1982. Macropores and water flow in soils. Water Res. Research. 18(5):1311-1325.

Borah, A.K. and C.T. Haan. 1989. Error distributions and parameter estimation in hydrologic modeling. ASAE Paper No. 89-2079. Amer. Soc. of Agricultural Engineers, St. Joseph, Mich.

Bouwer, E., J. Mercer, M. Kavanaugh, and F. Digiano. 1988. Coping with groundwater contamination. Journal WPCF 60(8):1415-1428.

Bretas, F.S. and D.A. Haith. 1990. Linear programming analysis of pesticide pollution of groundwater. Trans. of the ASAE 33(1):167-172.

Breteler, H., D.J. Greenwood, I. Petterson, J.S. Russel, D. Sauerbeck, F. van Dorp, H. van Keulen, and H.G. van der Meer. 1981. Soil plant relations. In: Frissel, M.J. and van Veen (eds.) Simulation of nitrogen behaviour of soil-plant systems. Pudoc, Centre for Agricultural Publishing and Documentation. Wageningen.

Carsel, R.F., L.A. Mulkey, M.N. Lorber, and L.B. Baskin. 1985. The pesticide root zone model (PRZM): A procedure for evaluating pesticide leaching threats to groundwater. Ecological Modelling 30:49-69.

Carsel, R.F., C.N. Smith, L.A. Mulkey, J.D. Dean and P. Jowise. 1984. Users manual for the pesticide root zone model (PRZM) release 1. EPA-600/3-84-109. U.S. Environmental Protection Agency, Athens, Ga.

Crowder, B.M., H.B. Pionke, D.J. Epp, and C.E. Young. 1985. Using CREAMS and economic modeling to evaluate conservation practices. An application. J. Environ. Qual. 14:428-434.

Davis, F.M., R.A. Leonard, and W.G. Knisel. 1990. GLEAMS: User manual, version 1.8.55. USDA-ARS Southeast Watershed Research Laboratory, Tifton, Ga.

Dick, W.A. and T.C. Daniel. 1987. Soil chemical and biological properties as effected by conservation tillage: environmental implications. In: Logan, T.J., J.M. Davidson, J.L. Baker, and M.R. Overcash (ed.). Effects of conservation tillage on groundwater quality. Lewis Publishers, Inc., Chelsea, Mich.

Diebel, P.L. 1990. An economic analysis of low-input agriculture as a groundwater management strategy. Unpublished Ph.D. Dissertation, Dept. of Agricultural Econ., V.P.I. & S.U., Blacksburg, Va. 24061.

Donigian, A.S. Jr., and P.S.C. Rao. 1986. Overview of terrestrial processes and modeling. In: Hern, S.C. and S.M. Melanchon (ed.) Vadose zone modeling of organic pollutants. Lewis Publishers, Inc., Chelsea, Mich.

Ferreira, V.A. and R.E. Smith. 1988. The limited physical basis of physically based hydrologic models. In: Modeling agricultural, forest, and rangeland hydrology. Publ. 07-88. Amer. Soc. of Agricultural Engineers, St. Joseph, Mich.

Flanagan, D.C., W.H. Neibling, G.R. Foster, and J.P. Hurt. 1986. Application of CREAMS in filter strip design. ASAE Paper No. 86-2043. Amer. Soc. of Agricultural Engineers, St. Joseph, Mich.

Foutz, R. 1990. Statistical Consultant, Virginia Polytechnic Institute and State University, Blacksburg, Va. Personal communication with Peter E. Davis.

Frere, M.H., J.D. Ross, and L.J. Lane. 1980. Chapter 4. The nutrient submodel. In: Knisel W.G. (ed.) CREAMS: A field scale model for chemicals, runoff, and erosion from agricultural management systems. Conservation Research Report No. 26. USDA, Washington, D.C. p. 65-87.

Frissel, M.J. and van Veen (eds.) 1980. Simulation of nitrogen behaviour of soil-plant systems. Pudoc, Centre for Agricultural Publishing and Documentation. Wageningen.

Gibbons, J.D. 1985. Nonparametric statistical inference. Second edition. Marcel Dekker, Inc., New York, NY.

Gilliam, J.W., and G.D. Hoyt. 1987. In: Logan, T.J., J.M. Davidson, J.L. Baker, and M.R. Overcash (ed.). Effects of conservation tillage on groundwater quality. Lewis Publishers, Inc., Chelsea, Mich.

Gish, T.J., and C.B. Coffman. 1987. Solute transport under no-till field corn. Trans. of the ASAE 30(5):1358-1363.

Glotfelty, D.E. 1987. The effect of conservation tillage practices on pesticide volatilization and degradation. In: Logan, T.J., J.M. Davidson, J.L. Baker, and M.R. Overcash (ed.) Effects of conservation tillage on groundwater quality. Lewis Publishers, Inc., Chelsea, Mich.

Heatwole, C.D. 1990. Agricultural Engineer, Virginia Polytechnic Institute and State University, Blacksburg, Va. Personal communication with Peter E. Davis.

Heatwole, C.D., P.L. Diebel, and J.M. Halstead. 1990. Management and policy effects on potential groundwater contamination from dairy waste. Water Resources Bulletin 26(1):25-34.

Hubbard, R.K. and R.A. Leonard. 1989. Nitrate movement through a sandy Coastal Plain soil. ASAE Paper No. 89-2503. Amer. Soc. of Agricultural Engineers, St. Joseph, Mich.

Hubbard, R.K. and J.M. Sheridan. 1983. Water and nitrate nitrogen losses from a small, upland coastal plain watershed. J. Environ. Qual. 12:291-295.

Hubbard, R.K., R.G. Williams, M.D. Erdman, and L.R. Marti. 1989. Chemical transport from Coastal Plain soils under simulated rainfall: II. Movement of Cyanazine, Sulfometuron-Methyl, and bromide. Transactions of the ASAE 32(4): 1250-1257.

Jury, W.A., W.F. Spencer, and W.J. Farmer. 1983. Use of models for assessing relative volatility mobility and persistence of pesticides and other trace organics in soil systems. In: Saxena J. (ed.) Hazard assessment of chemicals: current developments volume 2. Academic Press, Inc. New York, NY.

Jury, W.A. and R.L. Valentine. 1987. Transport mechanisms and loss pathways for chemicals in soils. In: Hern, S.C. and S.M. Melanchon (ed.). Vadose zone modeling of organic pollutants. Lewis Publishers, Inc., Chelsea, Mich.

Knisel, W.G., ed. 1980. CREAMS: A field scale model for chemicals, runoff, and erosion from agricultural management systems. Conservation Research Report No. 26. U.S. Department of Agriculture, Washington, D.C. 640p.

Knisel, W.G., R.A. Leonard and F.M. Davis. 1989. Agricultural management alternatives: GLEAMS model simulations. Proceedings of the 1989 Summer Computer Simulation Conference. Austin, Tex.

Leonard, R.A., W.G. Knisel. 1988. Evaluating potential groundwater contamination from herbicide use. Weed Technology 2:207-216.

Leonard, R.A. and W.G. Knisel. 1989. Groundwater loadings by controlled-release pesticides: A GLEAMS simulation. Transactions of the ASAE 32(6):1915-1922

Leonard, R.A., A. Shirmohammadi, A.W. Johnson and L.R. Marti. 1986. Pesticide transport in shallow groundwater. ASAE Paper No. 86-2508. Amer. Soc. of Agricultural Engineers, St. Joseph, Mich.

Leonard, R.A., W.G. Knisel and D.A. Still. 1987. GLEAMS: groundwater loading effects of agricultural management systems. Transactions of the ASAE 30(5):1403-1418.

Mostaghimi, S., U.S. Tim, P.W. McClellan, J.C. Carr, R.K. Byler, T.A. Dillaha, V.O. Shanholtz, and J.R. Pratt. 1989. Watershed/Water quality monitoring for evaluating BMP effectiveness - Nomini Creek Watershed. Pre-BMP Evaluation Final Report, Department of Conservation and Historic Resources, Division of Soil and Water Conservation, Richmond, Va.

Nicks, A.D., J.B. Burt, W.G. Knisel, and G.A. Gander. 1984. Application of a field-scale water quality model for evaluation of a watershed land treatment project. ASAE Paper No. 84-2633. Amer. Soc. of Agricultural Engineers, St. Joseph, Mich.

Onstad, C.A. and W.B. Voorhees. 1987. Hydrologic soil parameters affected by tillage. In: Logan, T.J., J.M. Davidson, J.L. Baker, and M.R. Overcash (ed.). Effects of conservation tillage on groundwater quality. Lewis Publishers, Inc., Chelsea, Mich.

Rao, P.S.C. and J.M. Davidson. 1980. Estimation of pesticide retention and transformation parameters required in nonpoint source pollution models. In: Overcash, M.R. and J.M. Davidson (ed.) Environmental impact of nonpoint source pollution. Ann Arbor Science Publ., Ann Arbor, Mich.

Rao, P.S.C. and Jessup. 1982. Development and verification of simulation models for describing pesticide dynamics in soils. Ecol. Modelling 16:67-75.

Rao, P.S.C. and R.J. Wagenet. 1984. Spatial variability of pesticides in field soils: methods for data analysis and consequences. Weed Sci. 33 (suppl. 2):18-24.

Roka, F.M., B.V. Lessley, and W.L. Magette. 1989. Economic effects of soil conditions on farm strategies to reduce agricultural pollution. Water Resources Bulletin 25(4):821- 827.

Royal Society of Chemistry. 1987. The Agrochemicals Handbook, second edition. Hartley, D. and H. Kidd (eds.). University of Nottingham Press, Nottingham, England.

Scheffe, H. 1959. The analysis of variance. John Wiley & Sons, Inc. New York, NY.

Schepers, J.S. 1987. Effect of conservation tillage on processes affecting nitrogen management. In: Logan, T.J., J.M. Davidson, J.L. Baker, and M.R. Overcash (ed.). Effects of conservation tillage on groundwater quality. Lewis Publishers, Inc., Chelsea, MI.

Shaffer, M.J. 1985. Simulation model for soil erosion-productivity relationships. J. of Environ. Qual. 14:144-150.

Shanholtz, V.O. 1989. Unpublished Data. Information Support Systems Laboratory, Dept. of Agricultural Engineering, V.P.I. & S.U., Blacksburg, Va.

Shirmohammadi, A., W.L. Magette, R.B. Brinsfield and K. Staver. 1987. Groundwater loading of agrichemicals in the Coastal Plain region. ASAE Paper No. 87-2632. Amer. Soc. of Agricultural Engineers, St. Joseph, Mich.

Shirmohammadi, A. and R.G. Williams. 1987. Cover conditions and hydrologic response of a Coastal Plain soil. ASAE Paper No. 87-2059, Amer. Soc. of Agricultural Engineers, St. Joseph, Mich.

Smith, M.C., K.L. Campbell, A.B. Bottcher and D.L. Thomas. 1989. Field testing and comparison of the PRZM and GLEAMS models. ASAE Paper No. 89-2072. Amer. Soc. of Agricultural Engineers, St. Joseph, Mich.

Soil Conservation Service. 1984. User's guide for the CREAMS computer model. U.S. Department of Agriculture, Soil Conservation Service, TR-72.

Storm, D.E., T.A. Dillaha, S. Mostaghimi and V.O. Shanholtz. 1988. Modeling phosphorous transport in surface runoff. Trans. of the ASAE 31(1):117-127.

Thomas, D.L., M.C. Smith, R.A. Leonard and F.J.K. daSilva. 1990. Simulated effects of rapeseed production alternatives on pollution potential in the Georgia Coastal Plain. J. Soil and Water Conserv. 45(1):148-154.

USDA-SCS. . 1983. Soil survey of Richmond County, Virginia. Soil Cons. Serv., U.S. Department of Agriculture, Washington, D.C.

Verschueren, K. 1983. Handbook of environmental data on organic chemicals, second edition. Van Nostrand Reinhold Company, Inc. New York.

Wagenet, R.J. and P.S.C. Rao. 1985. Basic concepts of modeling pesticide fate in the crop root zone. Weed Sci. 33 (suppl. 2):25-32.

Wauchope, R.D. 1988. USDA-ARS interim pesticide properties database, version 1.0. U.S. Department of Agriculture, Agricultural Res. Serv., Washington, D.C.

Williams, R.D. and A.D. Nicks. 1988. Using CREAMS to simulate filter strip effectiveness in erosion control. J. of Soil and Water Conserv. 43(1):108-112.

Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson. 1987. AGNPS, agricultural nonpoint-source pollution model: A watershed analysis tool. U.S. Department of Agriculture, Agricultural Res. Serv., Conservation Research Report No. 35, Washington, D.C. 80p.

Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson. 1989. AGNPS: a nonpoint source pollution model for evaluating agricultural watersheds. J. Soil and Water Conserv. 44(2): 168-173.

APPENDICES

APPENDIX A: ROTATION SCHEDULES

Rotation[+]	Date(yr.)	Activity	N Application (kg/ha)	POTM (kg/ha)[#]
1C1	Mar. 25(1)	Plow-incorporate	26.9	64.0
(2-year)	Apr. 10	Plant corn		
	May 10	Surface trickle	100.0	
	Sept. 20	Combine corn		
	Sept. 27	Plow-incorporate	5.2	42.0
	Oct. 15	Plant wheat		
	Feb. 20(2)	Surface spray	80.0	
	June 15	Combine wheat/ No-Till plant soybeans		
	Nov. 15	Combine soybeans		
1L2	Mar. 25(1)	Plow-incorporate	50.8	140.3
	Sept. 27	Plow-incorporate	34.1	93.2
1C3	Mar. 25(1)	Plow-incorporate	33.8	64.0
	May 10	Surface trickle	112.5	
	Sept. 27	Plow-incorporate	16.9	42.0
	Feb. 20(2)	Surface spray	73.1	
1L4	Mar. 25(1)	Plow-incorporate	58.5	151.8
	Sept. 27	Plow-incorporate	36.0	96.0
2C1	Mar. 25(1)	Surface broadcast	49.4	64.0
(2-year)	Apr. 10	No-Till plant corn		
	May 10	Surface trickle	100.0	
	Sept. 20	Combine corn		
	Sept. 27	Plow-incorporate	27.0	42.0
	Oct. 15	Plant wheat		
	Feb. 20(2)	Surface spray	100.0	
	June 15	Combine wheat/ Disk-plant soybeans		
	Nov. 15	Combine soybeans		
2L2	Mar. 25(1)	Surface broadcast	59.9	154.0
	Sept. 27	Plow-incorporate	50.8	118.0

Rotation*	Date(yr.)	Activity	N Application (kg/ha)	POTM (kg/ha)#
2C3	Mar. 25(1)	Surface broadcast	22.5	64.0
	May 10	Surface trickle	146.3	
	Sept. 27	Plow-incorporate	64.1	42.0
	Feb. 20(2)	Surface spray	67.5	
2L4	Mar. 25(1)	Surface broadcast	67.5	165.3
	Sept. 27	Plow-incorporate	52.7	121.0
3C1 (2-year)	Mar. 25(1)	Chisel plow	13.4	64.0
	Apr. 10	Plant corn		
	May 10	Surface trickle	80.0	
	May 15	Cultivate corn		
	Sept. 20	Combine corn		
	Sept. 27	Plow-incorporate	10.9	42.0
	Oct. 15	Plant wheat		
	Feb. 20(2)	Surface spray	70.0	
	June 15	Combine wheat/ No-Till plant soybeans		
	Nov. 15	Combine soybeans		
3L2	Mar. 25(1)	Chisel plow	37.4	120.0
	Sept. 27	Plow-incorporate	32.3	90.4
3C3	Mar. 25(1)	Chisel plow	33.8	64.0
	May 10	Surface trickle	78.8	
	Sept. 27	Plow-incorporate	18.0	42.0
	Feb. 20(2)	Surface spray	51.8	
3L4	Mar. 25(1)	Chisel plow	45.5	131.5
	Sept. 27	Plow-incorporate	27.9	83.9

Rotation*	Date(yr.)	Activity	N Application (kg/ha)	POTM (kg/ha)#
4C1	Mar. 25(1)	Plow-incorporate	26.9	64.0
(2-year)	Apr. 10	Plant corn		
	May 10	Surface trickle	100.0	
	Sept. 20	Combine corn		
	Sept. 27	Plow-incorporate	7.2	42.0
	Oct. 15	Plant wheat		
	Feb. 20(2)	Surface spray	35.0	
	Mar. 20	Surface trickle	40.0	
	June 15	Combine wheat/ No-Till plant soybeans		
	Nov. 15	Combine soybeans		
4C3	Mar. 25(1)	Plow-incorporate	33.8	64.0
	May 10	Surface trickle	112.5	
	Sept. 27	Plow-incorporate	16.9	42.0
	Feb. 20(2)	Surface spray	39.4	
	Mar. 20	Surface trickle	33.8	
5L2	Mar. 25(1)	Disk-incorporate	50.8	140.2
(2-year)				
	Apr. 10	Plant corn		
	Apr. 30	Cultivate corn 2x		
	May 15	Cultivate corn 1x		
	Sept. 20	Combine corn		
	Sept. 27	Plow-incorporate	32.3	74.3
	Oct. 15	Plant wheat		
	June 15	Combine wheat/ No-Till plant soybeans		
	July 1-30	Cultivate soybeans 3x		
	Nov. 15	Combine soybeans		
5L4	Mar. 25(1)	Disk-incorporate	58.5	151.8
	Sept. 27	Plow-incorporate	34.2	93.3

Rotation*	Date(yr.)	Activity	N Application (kg/ha)	POTM (kg/ha)#
8C1 (2-year)	Apr. 5(1)	Mow rye		86.5
	Apr. 15	No-Till plant corn-inject	30.2	
	May 15	Cultivate corn 1x		
	June 15	Surface trickle	110.0	
	Sept. 27	Combine corn		
	Sept. 30	Plow-incorporate	6.2	42.0
	Oct. 15	Plant wheat		
	Feb. 20(2)	Surface spray	80.0	
	June 15	Combine wheat/ No-Till plant soybeans		7.4
	Sept. 15	Overseed soybeans with rye		
	Nov. 15	Combine soybeans		
8L2	Apr. 5(1)	Mow rye		86.5
	Apr. 15(1)	No-Till plant corn-inject	56.0	84.0
	Sept. 30	Plow-incorporate	34.5	93.7
	June 15(2)	Combine wheat/ No-Till plant soybeans		7.4
8C3	Apr. 5(1)	Mow rye		86.5
	Apr. 15	No-Till plant corn-inject	33.8	
	June 15	Surface trickle	112.5	
	Sept. 30	Plow-incorporate	16.9	42.0
	Feb. 20(2)	Surface Spray	73.1	
	June 15	Combine wheat/ No-Till plant soybeans		7.4
8L4	Apr. 5(1)	Mow rye		86.5
	Apr. 15(1)	No-Till plant corn-inject	58.5	87.0
	Sept. 30	Plow-incorporate	36.0	96.0
	June 15(2)	Combine wheat/ No-Till plant soybeans		7.4
11L2 (2-year)	Apr. 5(1)	Mow rye		86.5
	Apr. 15	No-Till plant corn-inject	56.1	84.1
	Apr. 30	Cultivate corn 2x		
	May 15	Cultivate corn 1x		
	Sept. 27	Combine corn		
	Sept. 30	Plow-incorporate	34.5	93.8
	Oct. 15	Plant wheat		
	June 15(2)	Combine wheat/ No-Till plant soybeans		7.4
	July 1-30	Cultivate soybeans 3x		
	Sept. 15	Overseed soybeans with rye		
	Nov. 15	Combine soybeans		

Rotation[*]	Date(yr.)	Activity	N Application (kg/ha)	POTM (kg/ha)[#]
12C1 (4-year)	Mar. 25(1)	Plow-incorporate	30.1	26.1
	Apr. 10	Plant corn		
	May 10	Surface trickle	109.0	
	Sept. 20	Combine corn		
	Sept. 27	Plow-incorporate	5.8	42.0
	Oct. 15	Plant wheat		
	Feb. 20(2)	Surface spray	80.0	
	June 15	Combine wheat/ No-Till plant soybeans		7.4
	Nov. 15	Combine soybeans		
	May 13(3)	Plow-incorporate residue		59.0
	May 20	Plant soybeans		
	Oct. 20	Combine soybeans		
	Oct. 25	Plow-incorporate	5.6	64.0
	Oct. 30	Plant wheat		
	Feb. 20(4)	Surface spray	60.0	
	June 15	Combine wheat/ No-Till plant soybeans		7.4
	Nov. 15	Combine soybeans		
12L2	Mar. 25(1)	Plow-incorporate	55.6	109.5
	Sept. 27	Plow-incorporate	34.3	93.6
	June 15(2)	Combine wheat/ No-Till plant soybeans		7.4
	May 13(3)	Plow incorporate residue		59.0
	Oct. 25	Plow-incorporate	26.3	103.4
	June 15(4)	Combine wheat/ No-Till plant soybeans		7.4
12C3	Mar. 25(1)	Plow-incorporate	33.8	26.1
	May 10	Surface trickle	112.5	
	Sept. 27	Plow-incorporate	16.9	42.0
	Feb. 20(2)	Surface spray	73.1	
	June 15	Combine wheat/ No-Till plant soybeans		7.4
	May 13(3)	Plow-incorporate	11.2	59.0
	Oct. 25	Plow-incorporate	16.9	64.0
	Oct. 30	Plant wheat		
	Feb. 20(4)	Surface spray	73.1	
	June 15	Combine wheat/ No-Till plant soybeans		7.4
12L4	Mar. 25(1)	Plow-incorporate	58.5	113.9
	Sept. 27	Plow-incorporate	36.0	96.0
	June 15(2)	Combine wheat		7.4
	May 13(3)	Plow incorporate	4.5	65.8
	Oct. 25	Plow-incorporate	36.0	118.0
	June 15(4)	Combine wheat/ No-Till plant soybeans		7.4

Rotation*	Date(yr.)	Activity	N Application (kg/ha)	POTM (kg/ha)#
15C1 (2-year)	Apr. 5(1)	Disk under rye & clover mix		131.5
	Apr. 15	Disk-incorporate	5.7	
	Apr. 25	Plant corn		
	June 15	Surface trickle	100.0	
	Sept. 27	Combine corn		
	Sept. 30	Plow-incorporate	5.5	42.0
	Oct. 15	Plant wheat		
	Feb. 20(2)	Surface spray	75.0	
	June 15	Combine wheat/ No-Till plant soybeans		7.4
	Sept. 15	Overseed soybeans with rye + clover		
	Nov. 15	Combine soybeans		
15L2	Apr. 5(1)	Disk under rye & clover mix		131.5
	Apr. 15(1)	Disk-incorporate	42.2	63.3
	Sept. 30	Plow-incorporate	32.2	90.0
	June 15(2)	Combine wheat/		7.4
15C3	Apr. 5(1)	Disk under rye & clover mix		131.5
	Apr. 15	Disk-incorporate	33.8	
	June 15	Surface trickle	112.5	
	Sept. 30	Plow-incorporate	16.9	42.0
	Feb. 20(2)	Surface Spray	73.1	
	June 15	Combine wheat		7.4
15L4	Apr. 5(1)	Disk under rye & clover mix		131.5
	Apr. 15(1)	Disk-incorporate	58.5	87.8
	Sept. 30	Plow-incorporate	inorganic N = 36.0	96.0
	June 15(2)	Combine wheat		7.4
16L2 (2-year)	Apr. 5(1)	Disk under rye & clover mix		131.5
	Apr. 15	Disk-incorporate	42.2	63.2
	Apr. 25	Plant corn		
	May 1-30	Cultivate corn 3x		
	Sept. 27	Combine corn		
	Sept. 30	Plow-incorporate	32.2	90.3
	Oct. 15	Plant wheat		
	June 15(2)	Combine wheat/ No-Till plant soybeans		7.4
	July 1-30	Cultivate soybeans 3x		
	Sept. 15	Overseed soybeans with rye		
	Nov. 15	Combine soybeans		

Rotation[*]	Date(yr.)	Activity	N Application (kg/ha)	POTM (kg/ha)[#]
16L4	Apr. 5(1)	Disk under rye & clover mix		131.5
	Apr. 15(1)	Disk-incorporate	58.5	87.8
	Sept. 30	Plow-incorporate	36.0	96.0
	June 15(2)	Combine wheat/		7.4

[*] C1 = Commercial fertilizer - N scenario 1; L2 = Poultry litter - N scenario 2
C3 = Commercial fertilizer - N scenario 3; L4 = Poultry litter - N scenario 4

[#] POTM = Potential Mineralizable Nitrogen of previous crop residues and/or poultry litter

APPENDIX B: PRECIPITATION SUMMARY

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL
				cm			
1951	3.7	4.3	6.8	7.8	7.7	11.8	13.3
52	13.7	7.3	10.1	11.9	8.3	7.4	6.7
53	10.0	8.3	11.1	8.4	10.8	3.6	3.4
54	9.8	3.0	7.3	5.3	9.1	1.3	6.6
55	2.5	7.4	10.7	10.7	7.8	15.0	7.3
56	5.7	8.4	7.5	7.8	6.1	7.1	16.5
57	8.2	8.7	9.4	6.6	5.0	11.9	2.9
58	9.7	11.5	14.9	13.0	12.1	10.5	12.1
59	3.1	4.0	7.1	10.0	1.8	2.8	31.0
60	5.3	9.5	6.6	8.5	17.7	2.7	14.3
61	8.9	13.1	11.8	5.7	16.1	13.9	6.1
62	12.5	8.8	11.0	10.4	6.2	14.8	11.2
63	4.6	4.6	15.4	0.4	6.6	17.5	1.7
64	8.8	12.6	6.6	12.4	1.9	10.0	9.2
65	6.0	5.1	8.8	5.7	3.2	13.5	18.4
66	8.1	9.4	2.1	8.7	7.4	9.6	8.1
67	4.8	6.1	6.0	3.0	10.8	2.3	16.2
68	6.7	1.3	13.7	3.8	11.0	16.1	7.5
69	8.3	7.7	8.0	8.9	11.0	5.5	14.6
70	2.9	4.9	8.3	6.9	8.6	11.0	13.6
71	6.6	8.6	4.9	4.4	20.9	9.5	8.4
72	6.0	13.4	5.5	8.4	18.9	26.6	13.0
73	5.8	8.4	5.5	11.3	8.0	4.5	11.6
74	9.4	3.5	12.4	4.7	10.0	5.7	12.7
75	10.9	6.4	15.2	7.2	8.9	15.5	20.6
76	12.3	2.6	5.9	2.5	13.5	8.0	8.9
77	5.1	2.9	4.8	4.1	8.9	3.2	5.9
78	19.3	1.1	12.1	10.2	23.6	8.7	5.3
79	14.7	13.7	6.5	7.8	16.4	8.5	15.8
80	7.7	2.1	11.0	8.8	7.0	2.6	11.1
81	0.7	7.7	3.4	8.6	15.2	9.0	12.2
82	8.5	9.1	7.1	7.4	3.7	10.5	9.7
83	3.7	5.7	15.2	18.3	13.2	8.5	4.1
84	10.3	6.0	26.8	10.5	18.0	4.8	9.6
85	6.5	8.3	2.6	0.8	9.2	5.9	5.4
AVG	7.7	7.0	9.2	7.7	10.4	9.1	10.7

PRECIPITATION SUMMARY (continued)

YEAR	AUG	SEP	OCT	NOV	DEC	TOTAL
	cm					
1951	7.4	6.8	5.6	13.4	9.8	98
52	6.6	8.7	6.4	11.6	8.8	108
53	12.0	3.8	7.0	4.3	6.8	90
54	8.4	1.6	5.6	6.8	7.4	72
55	30.2	13.9	6.7	5.0	2.1	119
56	5.7	20.3	12.8	16.7	7.5	122
57	15.8	8.2	16.3	9.7	13.9	117
58	19.9	6.1	12.1	8.4	11.1	141
59	4.9	5.8	13.2	19.1	7.3	110
60	15.3	20.2	8.0	3.0	7.6	119
61	7.2	9.0	21.5	4.1	13.0	130
62	11.3	10.0	2.0	17.4	7.3	123
63	4.0	6.4	0.0	15.2	5.0	81
64	15.4	8.6	6.7	5.8	7.2	105
65	6.1	8.5	2.8	1.1	0.9	80
66	3.5	28.4	13.2	3.7	8.0	110
67	16.5	3.7	3.6	5.1	12.9	91
68	10.7	3.1	4.8	7.3	4.7	91
69	28.6	9.1	3.3	4.1	15.9	125
70	1.4	3.2	4.3	0.0	6.7	72
71	10.4	3.2	22.0	9.1	2.1	110
72	5.1	10.0	11.7	13.2	9.3	141
73	7.5	6.6	8.0	3.6	13.1	94
74	18.0	12.7	1.4	3.3	10.4	104
75	8.6	28.7	9.8	7.7	8.5	148
76	5.8	22.9	20.2	3.7	5.0	111
77	6.0	13.1	14.1	7.7	15.0	91
78	12.6	1.2	1.2	8.1	9.8	113
79	22.4	31.2	7.5	13.0	5.0	163
80	2.4	4.0	17.4	6.7	1.5	82
81	7.9	11.2	5.8	2.5	8.2	92
82	16.6	5.4	5.8	11.1	6.8	102
83	5.6	10.8	13.0	12.0	13.6	124
84	7.3	2.2	7.5	9.6	3.3	116
85	29.0	21.2	12.3	14.6	1.4	117
AVG	11.3	10.6	9.0	8.2	7.9	109

APPENDIX C: HYDROLOGY and EROSION PARAMETER FILES USED in the CREAMS and GLEAMS SIMULATIONS

DAILY HYDROLOGY PARAMETERS - RICHMOND COUNTY
ROTATION ONE
CORN - CONVENTIONAL TILLAGE / DC SOYBEAN 2-YR ROTATION

```
     51001         0         1         1                   0
       1.0      0.28      0.44      0.30      3.50      0.40      0.08
       0.2      80.0     0.030       1.5      30.0
      0.27      1.33      1.60      1.60      1.60      1.60      1.60
      36.0      39.0      46.7      56.9      65.6      74.0      77.4      76.2
      69.9      59.1      49.3      40.0
     260.0     289.0     350.0     468.0     534.0     578.0     531.0     468.0
     388.0     300.0     228.0     189.0
      0.75
       001         0
       100         0
       116      0.07
       132      0.16
       148      0.19
       164      0.41
       180      0.96
       196      2.47
       212      2.49
       228      2.26
       244      1.52
       263         0
       291         0
       315      0.39
       339      0.75
       363      0.75
       366      0.75
         0         0         1
      0.75
       001      0.75
       061      0.75
       085      1.34
       110      2.49
       133      2.49
       152      0.80
       166         0
       176         0
       190      0.12
       204      0.33
       218      1.81
       232      2.47
       246      2.49
       260      2.46
       274      2.42
       288      1.91
       302      1.66
       319      0.42
       366         0
         0         0         1
              .
              .
              .
(above 2-yrs. Leaf Area Index repeated 17.5 times)
              .
              .
              .
        -1         0         0
```

CREAMS EROSION FILE, RICHMOND COUNTY, VA
1-ACRE FIELD; SUFFOLK SANDY LOAM
ROTATION 1 CORN/SMALL GRAIN - DC SOYBEAN (2 years)

```
        51        85         0         1         0         1         0

      0.15      0.25      0.60      0.01      20.0       4.0      0.05    1000.0
       1.0     200.0      0.03      0.03      0.03      0.03     200.0       0.0
     200.0       0.0
         1       1.0      0.20
         2
       001       084       100       130       175       220       263       270
       288       335
       075       105       166       196       226       258       319
         1       1.0
      0.42      0.56      0.83      0.70      0.54      0.31      0.44      0.53
      0.68      0.60
      1.00      1.00      1.00      1.00      1.00      1.00      1.00      1.00
      1.00      1.00
     0.020     0.046     0.023     0.014     0.012     0.010     0.010     0.046
     0.023     0.012
      0.45      0.26      0.26      0.24      0.22      0.17      0.36
      1.00      1.00      1.00      1.00      1.00      1.00      1.00
     0.015     0.023     0.023     0.014     0.012     0.010     0.010
```

DAILY HYDROLOGY PARAMETERS - RICHMOND COUNTY
ROTATION TWO
CORN - NO TILLAGE / DC SOYBEAN 2-YR ROTATION

```
51001       0         1         1                   0
  1.0     0.28      0.44      0.30      3.50      0.40      0.08
  0.2     77.0     0.030       1.5      30.0
 0.27     1.33      1.60      1.60      1.60      1.60      1.60
 36.0     39.0      46.7      56.9      65.6      74.0      77.4      76.2
 69.9     59.1      49.3      40.0
260.0    289.0     350.0     468.0     534.0     578.0     531.0     468.0
388.0    300.0     228.0     189.0
 0.60
  001        0
  100        0
  116     0.07
  132     0.16
  148     0.19
  164     0.41
  180     0.96
  196     2.47
  212     2.49
  228     2.26
  244     1.52
  263        0
  291        0
  315     0.39
  339     0.75
  363     0.75
  366     0.75
    0        0         1
 0.60
  001     0.75
  061     0.75
  085     1.34
  110     2.49
  133     2.49
  152     0.80
  166        0
  176        0
  190     0.12
  204     0.33
  218     1.81
  232     2.47
  246     2.49
  260     2.46
  274     2.42
  288     1.91
  302     1.66
  319     0.42
  366        0
    0        0         1
        .
        .
        .
(above 2-yrs. Leaf Area Index repeated 17.5 times)
        .
        .
        .
   -1        0         0
```

```
                CREAMS EROSION FILE, RICHMOND COUNTY, VA
                   1-ACRE FIELD; SUFFOLK SANDY LOAM
             ROTATION 2 CORN/SMALL GRAIN - DC SOYBEAN (2 years)
        51        85         0         1         0         1         0

      0.15      0.25      0.60      0.01      20.0       4.0      0.05    1000.0
       1.0     200.0      0.03      0.03      0.03      0.03     200.0       0.0
     200.0       0.0
         1       1.0      0.20
         2
       001       100       130       175       220       263       270       288
       335
       075       105       166       196       226       258       319
         1       1.0
      0.32      0.44      0.38      0.32      0.23      0.40      0.43      0.64
      0.56
      1.00      1.00      1.00      1.00      1.00      1.00      1.00      1.00
      1.00
     0.020     0.023     0.014     0.012     0.010     0.010     0.046     0.023
     0.012
      0.36      0.14      0.21      0.18      0.15      0.13      0.21
      1.00      1.00      1.00      1.00      1.00      1.00      1.00
     0.015     0.023     0.030     0.014     0.012     0.010     0.010
```

DAILY HYDROLOGY PARAMETERS - RICHMOND COUNTY
ROTATION THREE
CORN - CHISEL TILLAGE / DC SOYBEAN 2-YR ROTATION

```
51001       0       1       1               0
  1.0    0.28    0.44    0.30    3.50    0.40    0.08
  0.2    78.0   0.030     1.5    30.0
 0.27    1.33    1.60    1.60    1.60    1.60    1.60
 36.0    39.0    46.7    56.9    65.6    74.0    77.4    76.2
 69.9    59.1    49.3    40.0
260.0   289.0   350.0   468.0   534.0   578.0   531.0   468.0
388.0   300.0   228.0   189.0
 0.75
  001       0
  100       0
  116    0.07
  132    0.16
  148    0.19
  164    0.41
  180    0.96
  196    2.47
  212    2.49
  228    2.26
  244    1.52
  263       0
  291       0
  315    0.39
  339    0.75
  363    0.75
  366    0.75
    0       0       1
 0.75
  001    0.75
  061    0.75
  085    1.34
  110    2.49
  133    2.49
  152    0.80
  166       0
  176       0
  190    0.12
  204    0.33
  218    1.81
  232    2.47
  246    2.49
  260    2.46
  274    2.42
  288    1.91
  302    1.66
  319    0.42
  366       0
    0       0       1
        .
        .
        .
(above 2-yrs. Leaf Area Index repeated 17.5 times)
        .
        .
        .
   -1       0       0
```

```
                      CREAMS EROSION FILE, RICHMOND COUNTY, VA
                        1-ACRE FIELD; SUFFOLK SANDY LOAM
                 ROTATION 3 CORN/SMALL GRAIN - DC SOYBEAN (2 years)
        51        85         0         1         0         1         0

      0.15      0.25      0.60      0.01      20.0       4.0      0.05    1000.0
       1.0     200.0      0.03      0.03      0.03      0.03     200.0       0.0
     200.0       0.0
         1       1.0      0.20
         2
       001       084       100       135       175       220       263       270
       288       335
       075       105       166       196       226       258       319
         1       1.0
      0.42      0.51      0.51      0.51      0.44      0.28      0.44      0.53
      0.68      0.60
      1.00      1.00      1.00      1.00      1.00      1.00      1.00      1.00
      1.00      1.00
     0.020     0.030     0.023     0.018     0.012     0.010     0.010     0.046
     0.023     0.012
      0.45      0.26      0.26      0.24      0.22      0.17      0.36
      1.00      1.00      1.00      1.00      1.00      1.00      1.00
     0.015     0.023     0.023     0.014     0.012     0.010     0.010
```

DAILY HYDROLOGY PARAMETERS - RICHMOND COUNTY
ROTATION FIVE
CORN - DISK TILLAGE / DC SOYBEAN 2-YR ROTATION

```
     51001         0         1         1                   0
       1.0      0.28      0.44      0.30      3.50      0.40      0.08
       0.2      79.0     0.030       1.5      30.0
      0.27      1.33      1.60      1.60      1.60      1.60      1.60
      36.0      39.0      46.7      56.9      65.6      74.0      77.4      76.2
      69.9      59.1      49.3      40.0
     260.0     289.0     350.0     468.0     534.0     578.0     531.0     468.0
     388.0     300.0     228.0     189.0
      0.75
       001         0
       100         0
       116      0.07
       132      0.16
       148      0.19
       164      0.41
       180      0.96
       196      2.47
       212      2.49
       228      2.26
       244      1.52
       263         0
       291         0
       315      0.39
       339      0.75
       363      0.75
       366      0.75
         0         0         1
      0.75
       001      0.75
       061      0.75
       085      1.34
       110      2.49
       133      2.49
       152      0.80
       166         0
       176         0
       190      0.12
       204      0.33
       218      1.81
       232      2.47
       246      2.49
       260      2.46
       274      2.42
       288      1.91
       302      1.66
       319      0.42
       366         0
              .
              .
              .
(above 2-yrs. Leaf Area Index repeated 17.5 times)
              .
              .
              .
        -1         0         0
```

CREAMS EROSION FILE, RICHMOND COUNTY, VA
1-ACRE FIELD; SUFFOLK SANDY LOAM
ROTATION 5 CORN/SMALL GRAIN - DC SOYBEAN (2 years)

```
    51       85        0        1        0        1        0

  0.15     0.25     0.60     0.01     20.0      4.0     0.05   1000.0
   1.0    200.0     0.03     0.03     0.03     0.03    200.0      0.0
200.00.0
     1      1.0     0.20
     2
   001      084      100      135      175      220      263      270
288335
   075      105      166      196      226      258      319
     1      1.0
  0.42     0.58     0.58     0.58     0.44     0.28     0.44     0.53
0.680.60
  1.00     1.00     1.00     1.00     1.00     1.00     1.00     1.00
1.001.00
 0.020    0.040    0.023    0.018    0.012    0.010    0.010    0.046
0.0230.012
  0.45     0.26     0.26     0.25     0.22     0.17     0.36
  1.00     1.00     1.00     1.00     1.00     1.00     1.00
 0.015    0.023    0.023    0.020    0.012    0.010    0.010
```

DAILY HYDROLOGY PARAMETERS - RICHMOND COUNTY
ROTATION EIGHT
CORN - NO TILLAGE / DC SOYBEAN, RYE WC 2-YR ROTATION

```
 51001        0        1        1                 0
   1.0     0.28     0.44     0.30     3.50     0.40     0.08
   0.2     76.0    0.030      1.5     30.0
  0.27     1.33     1.60     1.60     1.60     1.60     1.60
  36.0     39.0     46.7     56.9     65.6     74.0     77.4     76.2
  69.9     59.1     49.3     40.0
 260.0    289.0    350.0    468.0    534.0    578.0    531.0    468.0
 388.0    300.0    228.0    189.0
  0.50
   001     1.31
   063     2.49
   073     2.49
   083     2.49
   093     0.95
   095        0
   100        0
   116     0.07
   132     0.16
   148     0.19
   164     0.41
   180     0.96
   196     2.47
   212     2.49
   228     2.26
   244     1.52
   263        0
   291        0
   315     0.39
   339     0.75
   363     0.75
   366     0.75
     0        0        1
  0.50
   001     0.75
   061     0.75
   085     1.34
   110     2.49
   133     2.49
   152     0.80
   166        0
   176        0
   190     0.12
   204     0.33
   218     1.81
   232     2.47
   246     2.49
   260     2.46
   274     2.79
   288     2.53
   302     2.39
   319     1.16
   338     0.75
   358     1.31
   366     1.31
     0        0        1
           .
           .
           .
(above 2-yrs. Leaf Area Index repeated 17.5 times)
           .
           .
           .
    -1        0        0
```

```
                  CREAMS EROSION FILE, RICHMOND COUNTY, VA
                    1-ACRE FIELD; SUFFOLK SANDY LOAM
            ROTATION 8 CORN/SMALL GRAIN - DC SOYBEAN (2 years)
    51       85        0        1        0        1        0

  0.15     0.25     0.60     0.01     20.0      4.0     0.05   1000.0
   1.0    200.0     0.03     0.03     0.03     0.03    200.0      0.0
 200.0      0.0
     1      1.0     0.20
     2
   001      105      135      175      220      273      288      335
   075      105      166      196      226      258      288      319
     1      1.0
  0.11     0.11     0.11     0.17     0.23     0.31     0.55     0.48
  1.00     1.00     1.00     1.00     1.00     1.00     1.00     1.00
 0.046    0.046    0.023    0.014    0.012    0.046    0.023    0.012
  0.31     0.12     0.21     0.20     0.18     0.13     0.11     0.11
  1.00     1.00     1.00     1.00     1.00     1.00     1.00     1.00
 0.015    0.023    0.023    0.014    0.012    0.010    0.012    0.032
```

DAILY HYDROLOGY PARAMETERS - RICHMOND COUNTY
ROTATION ELEVEN
CORN - NO TILLAGE / DC SOYBEAN, RYE WC 2-YR ROTATION

```
     51001         0         1         1                   0
       1.0      0.28      0.44      0.30      3.50      0.40      0.08
       0.2      78.0     0.030       1.5      30.0
      0.27      1.33      1.60      1.60      1.60      1.60      1.60
      36.0      39.0      46.7      56.9      65.6      74.0      77.4      76.2
      69.9      59.1      49.3      40.0
     260.0     289.0     350.0     468.0     534.0     578.0     531.0     468.0
     388.0     300.0     228.0     189.0
      0.50
       001      1.31
       063      2.49
       073      2.49
       083      2.49
       093      0.95
       095         0
       100         0
       116      0.07
       132      0.16
       148      0.19
       164      0.41
       180      0.96
       196      2.47
       212      2.49
       228      2.26
       244      1.52
       263         0
       291         0
       315      0.39
       339      0.75
       363      0.75
       366      0.75
         0         0         1
      0.50
       001      0.75
       061      0.75
       085      1.34
       110      2.49
       133      2.49
       152      0.80
       166         0
       176         0
       190      0.12
       204      0.33
       218      1.81
       232      2.47
       246      2.49
       260      2.46
       274      2.79
       288      2.53
       302      2.39
       319      1.16
       338      0.75
       358      1.31
       366      1.31
         0         0         1
           .
           .
           .
(above 2-yrs. Leaf Area Index repeated 17.5 times)
           .
           .
           .
        -1         0         0
```

CREAMS EROSION FILE, RICHMOND COUNTY, VA
1-ACRE FIELD; SUFFOLK SANDY LOAM
ROTATION 11 CORN/SMALL GRAIN - DC SOYBEAN (2 years)

```
     51        85         0         1         0         1         0

   0.15      0.25      0.60      0.01      20.0       4.0      0.05    1000.0
    1.0     200.0      0.03      0.03      0.03      0.03     200.0       0.0
  200.0       0.0
      1       1.0      0.20
      2
    001       105       120       135       175       220       273       288
    335
    075       105       166       196       226       258       288       319
      1       1.0
   0.11      0.11      0.20      0.19      0.19      0.23      0.31      0.55
   0.48
   1.00      1.00      1.00      1.00      1.00      1.00      1.00      1.00
   1.00
  0.046     0.046     0.030     0.020     0.012     0.010     0.046     0.023
  0.012
   0.31      0.12      0.21      0.20      0.18      0.13      0.11      0.11
   1.00      1.00      1.00      1.00      1.00      1.00      1.00      1.00
  0.015     0.023     0.023     0.014     0.012     0.010     0.012     0.032
```

DAILY HYDROLOGY PARAMETERS - RICHMOND COUNTY
ROTATION TWELVE
CORN/SOYBEANS - CONVENTIONAL TILLAGE DC SOYBEAN 4-YR ROTATION

```
51001       0       1       1               0
  1.0    0.28    0.44    0.30    3.50    0.40    0.08
  0.2    81.0   0.030     1.5    30.0
 0.27    1.33    1.60    1.60    1.60    1.60    1.60
 36.0    39.0    46.7    56.9    65.6    74.0    77.4    76.2
 69.9    59.1    49.3    40.0
260.0   289.0   350.0   468.0   534.0   578.0   531.0   468.0
388.0   300.0   228.0   189.0
 0.75
  001       0
  100       0
  116    0.07
  132    0.16
  148    0.19
  164    0.41
  180    0.96
  196    2.47
  212    2.49
  228    2.26
  244    1.52
  263       0
  291       0
  315    0.39
  339    0.75
  363    0.75
  366    0.75
    0       0
 0.75
  001    0.75
  061    0.75
  085    1.34
  110    2.49
  133    2.49
  152    0.80
  166       0
  176       0
  190    0.12
  204    0.33
  218    1.81
  232    2.47
  246    2.49
  260    2.46
  274    2.42
  288    1.91
  302    1.66
  319    0.42
  366       0
    0       0       1
```

```
 0.75
  001           0
  140           0
  155        0.12
  170        0.33
  185        1.81
  200        2.47
  215        2.49
  230        2.46
  245        2.42
  260        1.91
  275        1.66
  293        0.42
  300           0
  324        0.39
  348        0.75
  366        0.75
    0           0            1
 0.75
  001        0.75
  007        0.75
  031        0.75
  055        0.75
  085        1.34
  110        2.49
  133        2.49
  152        0.80
  175           0
  190        0.12
  204        0.33
  218        1.81
  232        2.47
  246        2.49
  260        2.46
  274        2.42
  288        1.91
  302        1.66
  319        0.42
  366           0
    0           0            1
            .
            .
            .
(above 4-yrs. Leaf Area Index repeated 8.75 times)
            .
            .
            .
   -1           0            0
```

CREAMS EROSION FILE, RICHMOND COUNTY, VA
1-ACRE FIELD; SUFFOLK SANDY LOAM
ROTATION 12 CORN/SMALL GRAIN/SOYBEANS - DC SOYBEAN (4 years)

```
      51        85         0         1         0         1         0

    0.15      0.25      0.60      0.01      20.0       4.0      0.05    1000.0
     1.0     200.0      0.03      0.03      0.03      0.03     200.0       0.0
   200.0       0.0
       1       1.0      0.20
       4
     001       084       100       130       175       220       273       288
     335
     075       105       166       196       226       258       319
     133       140       170       210       250       294       298       335
     075       105       166       196       226       258       319
       1       1.0
    0.42      0.56      0.83      0.70      0.54      0.31      0.53      0.68
    0.60
    1.00      1.00      1.00      1.00      1.00      1.00      1.00      1.00
    1.00
   0.020     0.046     0.023     0.014     0.012     0.010     0.046     0.023
   0.012
    0.45      0.26      0.26      0.24      0.22      0.17      0.36
    1.00      1.00      1.00      1.00      1.00      1.00      1.00
   0.015     0.023     0.023     0.014     0.012     0.010     0.010
    0.56      0.83      0.70      0.54      0.31      0.53      0.68      0.60
    1.00      1.00      1.00      1.00      1.00      1.00      1.00      1.00
   0.046     0.030     0.014     0.012     0.010     0.046     0.023     0.012
    0.45      0.26      0.26      0.24      0.22      0.17      0.36
    1.00      1.00      1.00      1.00      1.00      1.00      1.00
   0.015     0.023     0.023     0.014     0.012     0.010     0.010
```

DAILY HYDROLOGY PARAMETERS - RICHMOND COUNTY
ROTATION FIFTEEN
CORN - DISK TILLAGE / DC SOYBEAN, RYE & CLOVER WC 2-YR ROTATION

```
    51001         0         1         1                   0
      1.0      0.28      0.44      0.30      3.50      0.40      0.08
      0.2      77.0     0.030       1.5      30.0
     0.27      1.33      1.60      1.60      1.60      1.60      1.60
     36.0      39.0      46.7      56.9      65.6      74.0      77.4      76.2
     69.9      59.1      49.3      40.0
    260.0     289.0     350.0     468.0     534.0     578.0     531.0     468.0
    388.0     300.0     228.0     189.0
     0.50
      001      1.31
      063      2.49
      073      2.49
      083      2.49
      093      0.95
      095         0
      100         0
      116      0.07
      132      0.16
      148      0.19
      164      0.41
      180      0.96
      196      2.47
      212      2.49
      228      2.26
      244      1.52
      263         0
      291         0
      315      0.39
      339      0.75
      363      0.75
      366      0.75
        0         0         1
     0.50
      001      0.75
      061      0.75
      085      1.34
      110      2.49
      133      2.49
      152      0.80
      166         0
      176         0
      190      0.12
      204      0.33
      218      1.81
      232      2.47
      246      2.49
      260      2.46
      274      2.79
      288      2.53
      302      2.39
      319      1.16
      338      0.75
      358      1.31
      366      1.31
        0         0         1
                .
                .
                .
(above 2-yrs. Leaf Area Index repeated 17.5 times)
                .
                .
                .
       -1         0         0
```

CREAMS EROSION FILE, RICHMOND COUNTY, VA
1-ACRE FIELD; SUFFOLK SANDY LOAM
ROTATION 15 CORN/SMALL GRAIN - DC SOYBEAN (2 years)

```
     51        85         0         1         0         1         0

   0.15      0.25      0.60      0.01      20.0       4.0      0.05    1000.0
    1.0     200.0      0.03      0.03      0.03      0.03     200.0       0.0
  200.0       0.0
      1       1.0      0.20
      2
    001       095       105       115       145       190       235       273
    288       335
    075       105       166       196       226       258       288       319
      1       1.0
   0.11      0.21      0.25      0.25      0.23      0.22      0.14      0.31
   0.55      0.48
   1.00      1.00      1.00      1.00      1.00      1.00      1.00      1.00
   1.00      1.00
  0.046     0.046     0.046     0.030     0.023     0.014     0.012     0.046
  0.023     0.012
   0.31      0.12      0.21      0.20      0.18      0.13      0.11      0.11
   1.00      1.00      1.00      1.00      1.00      1.00      1.00      1.00
  0.015     0.023     0.023     0.014     0.012     0.010     0.012     0.032
```

DAILY HYDROLOGY PARAMETERS - RICHMOND COUNTY
ROTATION SIXTEEN
CORN - DISK TILLAGE / DC SOYBEAN, RYE & CLOVER WC 2-YR ROTATION

```
51001      0        1        1                 0
  1.0    0.28     0.44     0.30     3.50     0.40     0.08
  0.2    79.0    0.030      1.5     30.0
 0.27    1.33     1.60     1.60     1.60     1.60     1.60
 36.0    39.0     46.7     56.9     65.6     74.0     77.4     76.2
 69.9    59.1     49.3     40.0
260.0   289.0    350.0    468.0    534.0    578.0    531.0    468.0
388.0   300.0    228.0    189.0
 0.50
  001    1.31
  063    2.49
  073    2.49
  083    2.49
  093    0.95
  095       0
  100       0
  116    0.07
  132    0.16
  148    0.19
  164    0.41
  180    0.96
  196    2.47
  212    2.49
  228    2.26
  244    1.52
  263       0
  291       0
  315    0.39
  339    0.75
  363    0.75
  366    0.75
    0       0        1
 0.50
  001    0.75
  061    0.75
  085    1.34
  110    2.49
  133    2.49
  152    0.80
  166       0
  176       0
  190    0.12
  204    0.33
  218    1.81
  232    2.47
  246    2.49
  260    2.46
  274    2.79
  288    2.53
  302    2.39
  319    1.16
  338    0.75
  358    1.31
  366    1.31
    0       0        1
        .
        .
        .
```

(above 2-yrs. Leaf Area Index repeated 17.5 times)

```
        .
        .
        .
   -1       0        0
```

CREAMS EROSION FILE, RICHMOND COUNTY, VA
1-ACRE FIELD; SUFFOLK SANDY LOAM
ROTATION 16 CORN/SMALL GRAIN - DC SOYBEAN (2 years)

```
        51        85         0         1         0         1         0

      0.15      0.25      0.60      0.01      20.0       4.0      0.05    1000.0
       1.0     200.0      0.03      0.03      0.03      0.03     200.0       0.0
     200.0       0.0
         1       1.0      0.20
         2
       001       095       105       115       145       190       235       273
       288       335
       075       105       166       196       226       258       288       319
         1       1.0
      0.11      0.21      0.25      0.25      0.25      0.22      0.14      0.31
      0.55      0.48
      1.00      1.00      1.00      1.00      1.00      1.00      1.00      1.00
      1.00      1.00
     0.046     0.046     0.046     0.030     0.030     0.014     0.012     0.046
     0.023     0.012
      0.31      0.12      0.21      0.22      0.20      0.13      0.11      0.11
      1.00      1.00      1.00      1.00      1.00      1.00      1.00      1.00
     0.015     0.023     0.023     0.030     0.012     0.010     0.010     0.032
```

APPENDIX D: NUTRIENT PARAMETER FILES USED in the CREAMS SIMULATIONS

CREAMS Nutrient File, Richmond County, Virginia 1951-1985
Rotation 1, Scenario 1 - Commercial N
Plow-plant corn, Plow-Plant Wheat/No-Till Soybeans

```
     51001         0         0         0         1         0
      0.40      0.22      0.50
         2
       0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
      -0.2       7.4
      -0.2       0.8
     51001     51263
         2       110       263
     762.0    9400.0       2.5      64.0      60.0      27.0     160.0         1
     51084
      26.9      44.8      0.07
     51130
     100.0         0       1.0
     53001
     51288     52166
         2       298       166
     762.0    2000.0       3.7      42.0     160.0       8.0     110.0         1
     51270
       5.2      40.4      0.07
     52051
      80.0         0       1.0
     52166     52319
         0       176       319
     762.0      3020       4.2       7.4      60.0      20.0     180.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 52319 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia 1951-1985
Rotation 1, Scenario 2 - N from Poultry Litter
Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans

```
     51001         0         0         0         1         0
      0.40      0.22      0.50
         2
       0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
      -0.2       7.4
      -0.2       0.8
     51001     51263
         1       110       263
     762.0    9400.0       2.5     140.3      60.0      27.0     160.0         1
     51084
      50.8      44.8      0.07
     51288     52166
         1       298       166
     762.0    2000.0       3.7      93.2     160.0       8.0     110.0         1
     51270
      34.1      40.4      0.07
     52166     52319
         0       176       319
     762.0      3020       4.2       7.4      60.0      20.0     180.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 52319 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia
Rotation 1, Scenario 3 - Commercial N
Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans

```
      51001          0          0          0          1          0
       0.40       0.22       0.50
          2
        0.2        0.2       20.0     0.0018     0.0007      0.075      0.075        7.4
       -0.2        7.4
       -0.2        0.8
      51001      51263
          2        110        263
      762.0     9400.0        2.5       64.0       60.0       27.0      160.0          1
      51084
       33.6       44.8       0.07
      51130
      112.1          0        1.0
      51288      52166
          2        298        166
      762.0     2000.0        3.7       42.0      160.0        8.0      110.0          1
      51270
Wheat  16.8       40.4       0.07
      52051
       72.9          0        1.0
      52166      52319
          0        176        319
      762.0       3020        4.2        7.4       60.0       20.0      180.0          1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 52319 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia
Rotation 1, Scenario 4 - N from Poultry Litter
Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans

```
      51001          0          0          0          1          0
       0.40       0.22       0.50
          2
        0.2        0.2       20.0     0.0018     0.0007      0.075      0.075        7.4
       -0.2        7.4
       -0.2        0.8
      51001      51263
          1        110        263
      762.0     9400.0        2.5      151.8       60.0       27.0      160.0          1
      51084
       58.5       44.8       0.07
      51288      52166
          1        298        166
      762.0     2000.0        3.7       96.0      160.0        8.0      110.0          1
      51270
       36.0       40.4       0.07
      52166      52319
          0        176        319
      762.0       3020        4.2        7.4       60.0       20.0      180.0          1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 52319 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia 1951-1985
Rotation 2, Scenario 1 - Commercial N
No-Till Corn, Plow-Plant Wheat/Disk-Plant Soybeans

```
   51001         1         0         0         1         0
    0.40      0.22      0.50
       2
     0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
    -0.2       7.4
    -0.2       0.8
   51001     51263
       2       110       263
   762.0    9400.0       2.5      64.0      60.0      27.0     160.0         1
   51084
    49.4         0       1.0
   51130
   100.0         0       1.0
   51288     52166
       2       298       166
   762.0    2000.0       3.7      42.0     160.0       8.0     110.0         1
   51270
    27.0      40.4      0.07
   52051
   100.0         0       1.0
   52166     52319
       0       176       319
   762.0      3020       4.2       7.4      60.0      20.0     180.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 52319 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia 1951-1985
Rotation 2, Scenario 2 - N from Poultry Litter
No-Till Corn, Plow-Plant Wheat/Disk-Plant Soybeans

```
   51001         0         0         0         1         0
    0.40      0.22      0.50
       2
     0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
    -0.2       7.4
    -0.2       0.8
   51001     51263
       1       110       263
   762.0    9400.0       2.5     154.0      60.0      27.0     160.0         1
   51084
    59.9         0       1.0
   51288     52166
       1       298       166
   762.0    2000.0       3.7     118.0     160.0       8.0     110.0         1
   51270
    50.8      40.4      0.07
   52166     52319
       0       176       319
   762.0      3020       4.2       7.4      60.0      20.0     180.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 52319 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia
Rotation 2, Scenario 3 - Commercial N
2-year Rotation: Corn/Small Grain Double Cropped with Soybeans 1951-1985

```
   51001           0           0           0           1           0
    0.40        0.22        0.50
       2
     0.2         0.2        20.0      0.0018      0.0007       0.075       0.075         7.4
    -0.2         7.4
    -0.2         0.8
   51001       51263
       2         110         263
   762.0      9400.0         2.5        64.0        60.0        27.0       160.0           1
   51084
    22.4           0         1.0
   51130
   145.7           0         1.0
   51288       52166
       2         298         166
   762.0      2000.0         3.7        42.0       160.0         8.0       110.0           1
   51270
    63.9        40.4        0.07
   52051
    67.3           0         1.0
   52166       52319
       0         176         319
   762.0        3020         4.2         7.4        60.0        20.0       180.0           1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 52319 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia
Rotation 2, Scenario 4 - N from Poultry Litter
2-year Rotation: Corn/Small Grain Double Cropped with Soybeans 1951-1985

```
   51001           0           0           0           1           0
    0.40        0.22        0.50
       2
     0.2         0.2        20.0      0.0018      0.0007       0.075       0.075         7.4
    -0.2         7.4
    -0.2         0.8
   51001       51263
       1         110         263
   762.0      9400.0         2.5       165.3        60.0        27.0       160.0           1
   51084
    67.5        44.8         1.0
   51288       52166
       1         298         166
   762.0      2000.0         3.7       121.0       160.0         8.0       110.0           1
   51270
    52.7        40.4        0.07
   52166       52319
       0         176         319
   762.0        3020         4.2         7.4        60.0        20.0       180.0           1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 52319 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia 1951-1985
Rotation 3, Scenario 1 - Commercial N
Chisel-Plant Corn-Cultivate 1x, Plow-Plant Wheat/No-Till Soybeans

```
     51001         0         0         0         1         0
      0.40      0.22      0.50
         2
       0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
      -0.2       7.4
      -0.2       0.8
     51001     51263
         2       110       263
     762.0    9400.0       2.5      64.0      60.0      27.0     160.0         1
     51084
      13.4      44.8       0.1
     51130
      80.0         0       0.1
     51288     52166
         2       298       166
     762.0    2000.0       3.7      42.0     160.0       8.0     110.0         1
     51270
      10.9      44.8      0.07
     52051
      70.0         0       1.0
     52166     52319
         0       176       319
     762.0      3020       4.2       7.4      60.0      20.0     180.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 52319 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia1951-1985
Rotation 3, Scenario 2 - N from Poultry Litter
Chisel-Plant Corn-Cultivate 1x, Plow-Plant Wheat/No-Till Soybeans

```
     51001         0         0         0         1         0
      0.40      0.22      0.50
         2
       0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
      -0.2       7.4
      -0.2       0.8
     51001     51263
         1       110       263
     762.0    9400.0       2.5     120.0      60.0      27.0     160.0         1
     51084
      37.4      44.8       0.1
     51288     52166
         1       298       166
     762.0    2000.0       3.7      90.4     160.0       8.0     110.0         1
     51270
      32.3      44.8      0.07
     52166     52319
         0       176       319
     762.0      3020       4.2       7.4      60.0      20.0     180.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 52319 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia
Rotation 3, Scenario 3 - Commercial N
Chisel-Plant Corn-Cultivate 1x, Plow-Plant Wheat/No-Till Soybeans

```
  51001         0         0         0         1         0
   0.40      0.22      0.50
      2
    0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
   -0.2       7.4
   -0.2       0.8
  51001     51263
      2       110       263
  762.0    9400.0       2.5      64.0      60.0      27.0     160.0         1
  51084
   33.6      44.8       0.1
  51130
   78.8         0       0.1
  51288     52166
      2       298       166
  762.0    2000.0       3.7      42.0     160.0       8.0     110.0         1
  51270
   17.9      44.8      0.07
  52051
   51.8         0       1.0
  52166     52319
      0       176       319
  762.0      3020       4.2       7.4      60.0      20.0     180.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 52319 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia
Rotation 3, Scenario 4 - N from Poultry Litter
Chisel-Plant Corn-Cultivate 1x, Plow-Plant Wheat/No-Till Soybeans

```
  51001         0         0         0         1         0
   0.40      0.22      0.50
      2
    0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
   -0.2       7.4
   -0.2       0.8
  51001     51263
      1       110       263
  762.0    9400.0       2.5     131.5      60.0      27.0     160.0         1
  51084
   45.0      44.8       0.1
  51288     52166
      1       298       166
  762.0    2000.0       3.7      83.9     160.0       8.0     110.0         1
  51270
   27.9      40.4      0.07
  52166     52319
      0       176       319
  762.0      3020       4.2       7.4      60.0      20.0     180.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 52319 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia

Rotation 4, Scenario 1 - Commercial N (3-way split)
Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans

```
51001        0        0       0        1        0
 0.40     0.22     0.50
    2
  0.2      0.2     20.0  0.0018   0.0007    0.075    0.075    7.4
 -0.2      7.4
 -0.2      0.8
51001    51263
    2      110      263
762.0   9400.0      2.5    64.0     60.0     27.0    160.0      1
51084
 26.9     44.8     0.07
51130
100.0        0      1.0
51288    52166
    3      298      166
762.0   2000.0      3.7    42.0    160.0      8.0    110.0      1
51270
 7.25     40.4     0.07
52051
 35.0        0      1.0
52079
 40.0        0      1.0
52166    52319
    0      176      319
762.0     3020      4.2     7.4     60.0     20.0    180.0      1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 52319 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia

Rotation 4, Scenario 3 - Commercial N (3-way split)
Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans

```
51001        0        0       0        1        0
 0.40     0.22     0.50
    2
  0.2      0.2     20.0  0.0018   0.0007    0.075    0.075    7.4
 -0.2      7.4
 -0.2      0.8
51001    51263
    2      110      263
762.0   9400.0      2.5    64.0     60.0     27.0    160.0      1
51084
 33.6     44.8     0.07
51130
112.1        0      1.0
51288    52166
    3      298      166
762.0   2000.0      3.7    42.0    160.0      8.0    110.0      1
51270
 16.8     40.4     0.07
52051
 39.2        0      1.0
52079
 33.6        0      1.0
52166    52319
    0      176      319
762.0     3020      4.2     7.4     60.0     20.0    180.0      1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 52319 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia

Rotation 5, Scenario 2 - N from Poultry Litter
Disk-Plant Corn-Cultivate 3x, Plow-Plant Wheat/No-Till Soybeans-Cultivate 3x

```
  51001           0           0           0           1           0
   0.40        0.22        0.50
      2
    0.2         0.2        20.0      0.0018      0.0007       0.075       0.075         7.4
   -0.2         7.4
   -0.2         0.8
  51001       51263
      1         110         263
  762.0      9400.0         2.5       140.2        60.0        27.0       160.0           1
  51084
   50.8        44.8         0.1
  51288       52166
      1         298         166
  762.0      2000.0         3.7        90.5       160.0         8.0       110.0           1
  51270
   32.3        44.8        0.07
  52166       52319
      0         176         319
  762.0        3020         4.2         7.4        60.0        20.0       180.0           1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 52319 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia

Rotation 5, Scenario 4 - N from Poultry Litter
Disk-Plant Corn-Cultivate 3x, Plow-Plant Wheat/No-Till Soybeans-Cultivate 3x

```
  51001           0           0           0           1           0
   0.40        0.22        0.50
      2
    0.2         0.2        20.0      0.0018      0.0007       0.075       0.075         7.4
   -0.2         7.4
   -0.2         0.8
  51001       51263
      1         110         263
  762.0      9400.0         2.5       152.0        60.0        27.0       160.0           1
  51084
   58.5        44.8         0.1
  51288       52166
      1         298         166
  762.0      2000.0         3.7        93.0       160.0         8.0       110.0           1
  51270
   34.2        44.8        0.07
  52166       52319
      0         176         319
  762.0        3020         4.2         7.4        60.0        20.0       180.0           1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 52319 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia1951-1985
Rotation 8, Scenario 1 - Commercial N
No-Till Corn-Cultivate 1x, Plow-Plant Wheat/No-Till Soybeans, Rye Overseed

```
     51001         0         0         0         1         0
      0.40      0.22      0.50
         2
       0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
      -0.2       7.4
      -0.2       0.8
     51001     51270
         2       115       270
     762.0    9400.0       2.5      86.5      60.0      27.0     160.0         1
     51105
      30.2         0       0.2
     51166
     110.0         0       1.0
     51288     52166
         2       298       166
     762.0    2000.0       3.7      42.0     160.0       8.0     110.0         1
     51273
       6.2      40.4      0.07
     52051
      80.0         0       1.0
     52166     52319
         0       176       319
     762.0      3020       4.2       7.4      60.0      20.0     180.0         1
     52258     53095
         0       265       095
     600.0      2000       3.7       0.0      50.0       8.0      90.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 53095 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia1951-1985
Rotation 8, Scenario 2 - N from Poultry Litter
No-Till Corn-Cultivate 1x, Plow-Plant Wheat/No-Till Soybeans, Rye Overseed

```
     51001         0         0         0         1         0
      0.40      0.22      0.50
         2
       0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
      -0.2       7.4
      -0.2       0.8
     51001     51270
         1       115       270
     762.0    9400.0       2.5     170.4      60.0      27.0     160.0         1
     51105
      56.0         0       0.2
     51288     52166
         1       298       166
     762.0    2000.0       3.7      93.7     160.0       8.0     110.0         1
     51273
      34.5      40.4      0.07
     52166     52319
         0       176       319
     762.0      3020       4.2       7.4      60.0      20.0     180.0         1
     52258     53095
         0       265       095
     600.0      2000       3.7       0.0      50.0       8.0      90.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 53095 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia
Rotation 8, Scenario 3 - Commercial N
No-Till Corn-Cultivate 1x, Plow-Plant Wheat/No-Till Soybeans, Rye Overseed

```
     51001         0         0         0         1         0
      0.40      0.22      0.50
         2
       0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
      -0.2       7.4
      -0.2       0.8
     51001     51270
         2       115       270
     762.0    9400.0       2.5      86.5      60.0      27.0     160.0         1
     51105
      33.6      44.8       0.2
     51166
     112.1         0       1.0
     51288     52166
         2       298       166
     762.0    2000.0       3.7      42.0     160.0       8.0     110.0         1
     51273
      16.8      40.4      0.07
     52051
      72.9         0       1.0
     52166     52319
         0       176       319
     762.0      3020       4.2       7.4      60.0      20.0     180.0         1
     52258     53095
         0       265       095
     600.0      2000       3.7       0.0      50.0       8.0      90.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 53095 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia
Rotation 8, Scenario 4 - N from Poultry Litter
No-Till Corn-Cultivate 1x, Plow-Plant Wheat/No-Till Soybeans, Rye Overseed

```
     51001         0         0         0         1         0
      0.40      0.22      0.50
         2
       0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
      -0.2       7.4
      -0.2       0.8
     51001     51270
         1       115       270
     762.0    9400.0       2.5     174.3      60.0      27.0     160.0         1
     51105
      58.5      44.8       0.2
     51288     52166
         1       298       166
     762.0    2000.0       3.7      96.0     160.0       8.0     110.0         1
     51273
      36.0      40.4      0.07
     52166     52319
         0       176       319
     762.0      3020       4.2       7.4      60.0      20.0     180.0         1
     52258     53095
         0       265       095
     600.0      2000       3.7       0.0      50.0       8.0      90.0         1
      36.0      40.4      0.07
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 53095 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia
Rotation 11, Scenario 2 - N from Poultry Litter
No-Till Corn-Cultivate 3x, Plow-Plant Wheat/No-Till Soybeans-Cultivate 3x, Rye Overseed

```
     51001         0         0         0         1         0
      0.40      0.22      0.50
         2
       0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
      -0.2       7.4
      -0.2       0.8
     51001     51270
         1       115       270
     762.0    9400.0       2.5     170.6      60.0      27.0     160.0         1
     51105
      56.1      44.8       0.2
     51288     52166
         1       298       166
     762.0    2000.0       3.7      93.8     160.0       8.0     110.0         1
     51273
      34.5      40.4      0.07
     52166     52319
         0       176       319
     762.0      3020       4.2       7.4      60.0      20.0     180.0         1
     52258     53095
         0       265       095
     600.0      2000       3.7       0.0      50.0       8.0      90.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 53095 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia1951-1985
Rotation 12, Scenario 1 - Commercial N
Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans/Plow-Plant Soybeans, Plow-Plant Wheat/No-Till Soybeans

```
     51000         0         0         0         1         0
      0.40      0.22      0.50
         2
       0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
      -0.2       7.4
      -0.2       0.8
     51001     51270
         2       110       270
     762.0    9400.0       2.5      26.1      60.0      27.0     160.0         1
     51084
      30.1      44.8      0.07
     51130
     109.0         0       1.0
     51270     52166
         2       298       166
     762.0    2000.0       3.7      42.0     160.0       8.0     110.0         1
     51273
       5.8      40.4      0.07
     52051
      80.0         0       1.0
     52166     52319
         0       176       319
     762.0      3020       4.2       7.4      60.0      20.0     180.0         1
     53001     53293
         1       150       293
     762.0      3500       4.2      64.0      60.0      20.0     180.0         1
     53133
         0      33.6      0.07
     53293     54166
         2       309       166
     762.0      2000       3.7      59.0     160.0       8.0     110.0         1
     53298
       5.6      40.4      0.07
     54051
      60.0         0       1.0
     54166     54319
         0       176       319
     762.0      3020       4.2       7.4      60.0      20.0     180.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 54319 begins again at 55001 and is repeated every 4 years.

CREAMS Nutrient File, Richmond County, Virginia1951-1985
Rotation 12, Scenario 2 - N from Poultry Litter
Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans/Plow-Plant Soybeans, Plow-Plant Wheat/No-Till Soybeans

```
 51000         0         0         0         1         0
  0.40      0.22      0.50
     2
   0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
  -0.2       7.4
  -0.2       0.8
 51001     51270
     1       110       270
 762.0    9400.0       2.5     109.6      60.0      27.0     160.0         1
 51084
  55.6      44.8      0.07
 51270     52166
     1       298       166
 762.0    2000.0       3.7      93.6     160.0       8.0     110.0         1
 51273
  34.3      40.4      0.07
 52166     52319
     0       176       319
 762.0      3020       4.2       7.4      60.0      20.0     180.0         1
 53001     53293
     1       150       293
 762.0      3500       4.2      64.0      60.0      20.0     180.0         1
 53133
     0      33.6      0.07
 53293     54166
     1       309       166
 762.0      2000       3.7      98.4     160.0       8.0     110.0         1
 53298
  26.3      40.4      0.07
 54166     54319
     0       176       319
 762.0      3020       4.2       7.4      60.0      20.0     180.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 54319 begins again at 53001 and is repeated every 4 years.

CREAMS Nutrient File, Richmond County, Virginia
Rotation 12, Scenario 3 - Commercial N
Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans/Plow-Plant Soybeans, Plow-Plant Wheat/No-Till Soybeans

```
   51000         0         0         0         1         0
    0.40      0.22      0.50
       2
     0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
    -0.2       7.4
    -0.2       0.8
   51001     51270
       2       110       270
   762.0    9400.0       2.5      26.1      60.0      27.0     160.0         1
   51084
    33.8      44.8      0.07
   51130
   112.5         0       1.0
   51270     52166
       2       298       166
   762.0    2000.0       3.7      42.0     160.0       8.0     110.0         1
   51273
    16.9      40.4      0.07
   52051
    73.1         0       1.0
   52166     52319
       0       176       319
   762.0      3020       4.2       7.4      60.0      20.0     180.0         1
   53001     53293
       1       150       293
   762.0      3500       4.2      64.0      60.0      20.0     180.0         1
   53133
    11.2      33.6      0.07
   53293     54166
       2       309       166
   762.0      2000       3.7      59.0     160.0       8.0     110.0         1
   53298
    16.9      40.4      0.07
   54051
    73.1         0       1.0
   54166     54319
       0       176       319
   762.0      3020       4.2       7.4      60.0      20.0     180.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 54319 begins again at 53001 and is repeated every 4 years.

CREAMS Nutrient File, Richmond County, Virginia
Rotation 12, Scenario 4 - N from Poultry Litter

Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans/Plow-Plant Soybeans, Plow-Plant Wheat/No-Till Soybeans

```
 51000         0         0         0         1         0
  0.40      0.22      0.50
     2
   0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
  -0.2       7.4
  -0.2       0.8
 51001     51270
     1       110       270
 762.0    9400.0       2.5     113.9      60.0      27.0     160.0         1
 51084
  58.5      44.8      0.07
 51270     52166
     1       298       166
 762.0    2000.0       3.7      96.0     160.0       8.0     110.0         1
 51273
  36.0      40.4      0.07
 52166     52319
     0       176       319
 762.0      3020       4.2       7.4      60.0      20.0     180.0         1
 53001     53293
     1       150       293
 762.0      3500       4.2      70.8      60.0      20.0     180.0         1
 53133
   4.5      33.6      0.07
 53293     54166
     1       309       166
 762.0      2000       3.7      59.0     160.0       8.0     110.0         1
 53298
  36.0      40.4      0.07
 54166     54319
     0       176       319
 762.0      3020       4.2       7.4      60.0      20.0     180.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 54319 begins again at 53001 and is repeated every 4 years.

```
CREAMS Nutrient File, Richmond County, Virginia1951-1985
                         Rotation 15, Scenario 1 - Commercial N
          Disk-Plant Corn, Plow-Plant Wheat/No-Till Soybeans, Rye & Clover Overseed
 51001         0           0           0           1           0
  0.40       0.22        0.50
     2
   0.2        0.2        20.0      0.0018      0.0007       0.075       0.075        7.4
  -0.2        7.4
  -0.2        0.8
 51001      51270
     2        115         270
 762.0     9400.0         2.5       131.5        60.0        27.0       160.0          1
 51105
   5.7       44.8         0.1
 51161
 100.0          0         1.0
 51288      52166
     2        298         166
 762.0     2000.0         3.7        42.0       160.0         8.0       110.0          1
 51273
   5.5       40.4        0.07
 52051
  75.0          0         1.0
 52166      52319
     0        176         319
 762.0       3020         4.2         7.4        60.0        20.0       180.0          1
 52258      53095
     0        265         095
 600.0       2000         3.7         0.0        50.0         8.0        90.0          1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 53095 begins again at 53001 and is repeated every 2 years.

```
CREAMS Nutrient File, Richmond County, Virginia1951-1985
                    Rotation 15, Scenario 2 - N from Poultry Litter
          Disk-Plant Corn, Plow-Plant Wheat/No-Till Soybeans, Rye & Clover Overseed
 51001         0           0           0           1           0
  0.40       0.22        0.50
     2
   0.2        0.2        20.0      0.0018      0.0007       0.075       0.075        7.4
  -0.2        7.4
  -0.2        0.8
 51001      51270
     1        115         270
 762.0     9400.0         2.5       194.8        60.0        27.0       160.0          1
 51105
  42.2       44.8         0.1
 51288      52166
     1        298         166
 762.0     2000.0         3.7        90.0       160.0         8.0       110.0          1
 51273
  32.2       40.4        0.07
 52166      52319
     0        176         319
 762.0       3020         4.2         7.4        60.0        20.0       180.0          1
 52258      53095
     0        265         095
 600.0       2000         3.7         0.0        50.0         8.0        90.0          1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 53095 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia
Rotation 15, Scenario 3 - Commercial N
Disk-Plant Corn, Plow-Plant Wheat/No-Till Soybeans, Rye & Clover Overseed

```
 51001         0         0         0         1         0
  0.40      0.22      0.50
     2
   0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
  -0.2       7.4
  -0.2       0.8
 51001     51270
     2       115       270
 762.0    9400.0       2.5     131.5      60.0      27.0     160.0         1
 51105
  33.6      44.8       0.1
 51161
 112.1         0       1.0
 51288     52166
     2       298       166
 762.0    2000.0       3.7      42.0     160.0       8.0     110.0         1
 51273
  16.8      40.4      0.07
 52051
  72.9         0       1.0
 52166     52319
     0       176       319
 762.0      3020       4.2       7.4      60.0      20.0     180.0         1
 52258     53095
     0       265       095
 600.0      2000       3.7       0.0      50.0       8.0      90.0         1
     2       115       270
 762.0    9400.0       2.5     131.5      60.0      27.0     160.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 53095 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia
Rotation 15, Scenario 4 - N from Poultry Litter
Disk-Plant Corn, Plow-Plant Wheat/No-Till Soybeans, Rye & Clover Overseed

```
 51001         0         0         0         1         0
  0.40      0.22      0.50
     2
   0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
  -0.2       7.4
  -0.2       0.8
 51001     51270
     1       115       270
 762.0    9400.0       2.5     219.3      60.0      27.0     160.0         1
 51105
  58.5      44.8       0.1
 51288     52166
     1       298       166
 762.0    2000.0       3.7      96.0     160.0       8.0     110.0         1
 51273
  36.0      40.4      0.07
 52166     52319
     0       176       319
 762.0      3020       4.2       7.4      60.0      20.0     180.0         1
 52258     53095
     0       265       095
 600.0      2000       3.7       0.0      50.0       8.0      90.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 52319 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia
Rotation 16, Scenario 2 - N from Poultry Litter
Disk Corn-Cultivate 3x, Plow-Plant Wheat/No-Till Soybeans-Cultivate 3x, Rye & Clover Overseed

```
     51001         0         0         0         1         0
      0.40      0.22      0.50
         2
       0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
      -0.2       7.4
      -0.2       0.8
     51001     51270
         1       115       270
     762.0    9400.0       2.5     194.8      60.0      27.0     160.0         1
     51105
      42.2      44.8       0.1
     51288     52166
         1       298       166
     762.0    2000.0       3.7      90.3     160.0       8.0     110.0         1
     51273
      32.2      40.4      0.07
     52166     52319
         0       176       319
     762.0      3020       4.2       7.4      60.0      20.0     180.0         1
     52258     53095
         0       265       095
     600.0      2000       3.7       0.0      50.0       8.0      90.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 53095 begins again at 53001 and is repeated every 2 years.

CREAMS Nutrient File, Richmond County, Virginia
Rotation 16, Scenario 4 - N from Poultry Litter
Disk Corn-Cultivate 3x, Plow-Plant Wheat/No-Till Soybeans-Cultivate 3x, Rye & Clover Overseed

```
     51001         0         0         0         1         0
      0.40      0.22      0.50
         2
       0.2       0.2      20.0    0.0018    0.0007     0.075     0.075       7.4
      -0.2       7.4
      -0.2       0.8
     51001     51270
         1       115       270
     762.0    9400.0       2.5     219.3      60.0      27.0     160.0         1
     51105
      58.5      44.8       0.1
     51288     52166
         1       298       166
     762.0    2000.0       3.7      96.0     160.0       8.0     110.0         1
     51273
      36.0      40.4      0.07
     52166     52319
         0       176       319
     762.0      3020       4.2       7.4      60.0      20.0     180.0         1
     52258     53095
         0       265       095
     600.0      2000       3.7       0.0      50.0       8.0      90.0         1
```

NOTE: The sequence of parameters starting at Julian Day 51001 and ending at 52319 begins again at 53001 and is repeated every 2 years.

APPENDIX E: PESTICIDE PARAMETER FILES USED in the GLEAMS SIMULATIONS

GLEAMS Pesticide File, Richmond County, Virginia
Rotation 1
Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans

```
  51000      85365           8           2           0
      1                 Aatrex           0
      2                   Dual           0
      3                Harmony           0
      4              Gramoxone           0
      5            Chlorimuron           0
      6                Linuron           0
      7                 Pydrin           0
      8               Fusilade           0
      1       33.0         2.0       160.0         0.0        0.50         0.3
   60.0       60.0
      2      530.0         3.0       200.0         0.0        0.65         0.5
   20.0       20.0
      3     2400.0         0.5        10.0         0.0        0.50         0.8
   12.0       12.0
      4      1.0E6         3.0       1.0E5         0.0        0.40         1.0
 3600.0     3600.0
      5      500.0         3.0        20.0         0.0        0.50         0.5
   50.0       50.0
      6       75.0         3.0       863.0         0.0        0.50         0.3
   60.0       60.0
      7       0.10         7.0       1.0E5         0.0        0.40         0.0
   50.0       50.0
      8        2.0         3.0      3000.0         0.0        0.50         0.0
   20.0       20.0
   1100          2
      1       1.69         1.0         0.0        1.00           2
      2       1.13         1.0         0.0        1.00           2
   2051          1
      3       0.03         1.0        0.40        0.60           0
   2166          4
      2       1.13         1.0        0.50        0.50           0
      4       0.53         1.0        0.50        0.50           0
      5       0.02         1.0        0.50        0.50           0
      6       0.20         1.0        0.50        0.50           0
   2213          1
      8       0.22         1.0        0.65        0.35           0
   2244          1
      7       0.15         1.0        0.75        0.25           0
      0
```

(NOTE: 0 on the last line indicates end-of-file)

GLEAMS Pesticide File, Richmond County, Virginia
Rotation 2
No-Till Corn, Plow-Plant Wheat/Disk-Plant Soybeans

```
   51000      85365          10           2           0
       1                 Aatrex           0
       2                   Dual           0
       3                Harmony           0
       4              Gramoxone           0
       5                 Pydrin           0
       6                 Banvel           0
       7                  2,4-D           0
       8                Roundup           0
       9                 Blazer           0
      10                  Lorox           0
       1       33.0         2.0       160.0         0.0        0.50         0.3
    60.0       60.0
       2      530.0         3.0       200.0         0.0        0.65         0.5
    20.0       20.0
       3     2400.0         0.5        10.0         0.0        0.50         0.8
    12.0       12.0
       4      1.0E6         3.0       1.0E5         0.0        0.40         1.0
  3600.0     3600.0
       5       0.10         7.0       1.0E5         0.0        0.40         0.0
    50.0       50.0
       6      8.0E5         9.0         2.0         0.0        0.65         1.0
    14.0       14.0
       7      900.0         9.0        74.0         0.0        0.45         0.6
    10.0       10.0
       8      1.0E6         2.5     10000.0         0.0        0.65         0.9
    30.0       30.0
       9      9.0E5         3.0       139.0         0.0        0.50         1.0
    30.0       30.0
      10       75.0         3.0       863.0         0.0        0.50         0.3
    60.0       60.0
    1084          3
       1       2.25         1.0        0.50        0.50           0
       2       0.32         1.0        0.50        0.50           0
       4       0.32         1.0        0.50        0.50           0
    2051          3
       3       0.03         1.0        0.40        0.60           0
       6       0.28         1.0        0.40        0.60           0
       7       0.28         1.0        0.40        0.60           0
    2166          3
       2       1.69         1.0        0.30        0.70           0
       4       0.53         1.0        0.30        0.70           0
      10       0.56         1.0        0.30        0.70           0
    2186          2
       8       1.13         1.0        0.30        0.70           0
       9       0.42         1.0        0.30        0.70           0
    2244          1
       5       0.15         1.0        0.75        0.25           0
       0
```

(NOTE: 0 on the last line indicates end-of-file)

```
GLEAMS Pesticide File, Richmond County, Virginia
                                            Rotation 3
                      Chisel-Plant Corn-Cultivate 1x, Plow-Plant Wheat/No-Till Soybeans
 51000         85365          3           2           0
     1                   Aatrex           0
     2                Gramoxone           0
     3                 Fusilade           0
     1          33.0        2.0       160.0         0.0         0.50        0.3
  60.0          60.0
     2         1.0E6        3.0       1.0E5         0.0         0.40        1.0
3600.0        3600.0
     3           2.0        3.0      3000.0         0.0         0.50        0.0
  20.0          20.0
  1100             1
     1          1.69        1.0         0.3        0.70            2
  2166             1
     2          0.18        1.0        0.50        0.50            0
  2213             1
     3          0.22        1.0        0.65        0.35            0
     0
```

```
                           GLEAMS Pesticide File, Richmond County, Virginia
                                            Rotation 4
                            Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans
 51000         85365          8           2           0
     1                   Aatrex           0
     2                     Dual           0
     3                  Harmony           0
     4                Gramoxone           0
     5              Chlorimuron           0
     6                  Linuron           0
     7                   Pydrin           0
     8                 Fusilade           0
     1          33.0        2.0       160.0         0.0         0.50        0.3
  60.0          60.0
     2         530.0        3.0       200.0         0.0         0.65        0.5
  20.0          20.0
     3        2400.0        0.5        10.0         0.0         0.50        0.8
  12.0          12.0
     4         1.0E6        3.0       1.0E5         0.0         0.40        1.0
3600.0        3600.0
     5         500.0        3.0        20.0         0.0         0.50        0.5
  50.0          50.0
     6          75.0        3.0       863.0         0.0         0.50        0.3
  60.0          60.0
     7          0.10        7.0       1.0E5         0.0         0.40        0.0
  50.0          50.0
     8           2.0        3.0      3000.0         0.0         0.50        0.0
  20.0          20.0
  1100             2
     1          1.69        1.0         0.0        1.00            2
     2          1.13        1.0         0.0        1.00            2
  2051             1
     3          0.03        1.0        0.40        0.60            0
  2166             4
     2          1.13        1.0        0.50        0.50            0
     4          0.53        1.0        0.50        0.50            0
     5          0.02        1.0        0.50        0.50            0
     6          0.20        1.0        0.50        0.50            0
  2213             1
     8          0.22        1.0        0.65        0.35            0
  2244             1
     7          0.15        1.0        0.75        0.25            0
     0
```

GLEAMS Pesticide File, Richmond County, Virginia
Rotation 6
Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans

```
  51000       85365           9           2           0
      1                  Bladex           0
      2                   2,4-D           0
      3                    Dual           0
      4                 Harmony           0
      5               Gramoxone           0
      6             Chlorimuron           0
      7                 Linuron           0
      8                  Pydrin           0
      9                Fusilade           0
      1       171.0         2.0       168.0         0.0        0.60         0.4
   20.0        20.0
      2       900.0         9.0        74.0         0.0        0.45         0.6
   10.0        10.0
      3       530.0         3.0       200.0         0.0        0.65         0.5
   20.0        20.0
      4      2400.0         0.5        10.0         0.0        0.50         0.8
   12.0        12.0
      5       1.0E6         3.0       1.0E5         0.0        0.40         1.0
 3600.0      3600.0
      6       500.0         3.0        20.0         0.0        0.50         0.5
   50.0        50.0
      7        75.0         3.0       863.0         0.0        0.50         0.3
   60.0        60.0
      8        0.10         7.0       1.0E5         0.0        0.40         0.0
   50.0        50.0
      9         2.0         3.0      3000.0         0.0        0.50         0.0
   20.0        20.0
   1100           2
      1        1.80         1.0         0.0        1.00           2
      3        0.56         1.0         0.0        1.00           2
   1130           1
      2        0.56         1.0        0.10        0.90           0
   2051           1
      4        0.03         1.0        0.40        0.60           0
   2166           4
      3        1.13         1.0        0.50        0.50           0
      5        0.53         1.0        0.50        0.50           0
      6        0.02         1.0        0.50        0.50           0
      7        0.20         1.0        0.50        0.50           0
   2213           1
      9        0.22         1.0        0.65        0.35           0
   2244           1
      8        0.15         1.0        0.75        0.25           0
      0
```

(NOTE: 0 on the last line indicates end-of-file)

GLEAMS Pesticide File, Richmond County, Virginia
Rotation 7
Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans

```
     51000     85365          8         2          0
         1                Aatrex        0
         2                 Lasso        0
         3               Harmony        0
         4             Gramoxone        0
         5           Chlorimuron        0
         6               Linuron        0
         7                Pydrin        0
         8              Fusilade        0
         1      33.0        2.0     160.0        0.0       0.50       0.3
      60.0      60.0
         2     242.0        3.0     190.0        0.0       0.40       0.4
      14.0      14.0
         3    2400.0        0.5      10.0        0.0       0.50       0.8
      12.0      12.0
         4     1.0E6        3.0     1.0E5        0.0       0.40       1.0
    3600.0    3600.0
         5     500.0        3.0      20.0        0.0       0.50       0.5
      50.0      50.0
         6      75.0        3.0     863.0        0.0       0.50       0.3
      60.0      60.0
         7      0.10        7.0     1.0E5        0.0       0.40       0.0
      50.0      50.0
         8       2.0        3.0    3000.0        0.0       0.50       0.0
      20.0      20.0
      1100         2
         1      1.69        1.0       0.0       1.00          2
         2      2.25        1.0       0.0       1.00          2
      2051         1
         3      0.03        1.0      0.40       0.60          0
      2166         4
         2      2.25        1.0      0.50       0.50          0
         4      0.53        1.0      0.50       0.50          0
         5      0.02        1.0      0.50       0.50          0
         6      0.20        1.0      0.50       0.50          0
      2213         1
         8      0.22        1.0      0.65       0.35          0
      2244         1
         7      0.15        1.0      0.75       0.25          0
         0
```

(NOTE: 0 on the last line indicates end-of-file)

GLEAMS Pesticide File, Richmond County, Virginia
Rotation 17
Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans

```
  51000       85365           8           2           0
      1                  Aatrex           0
      2                    Dual           0
      3                 Harmony           0
      4                 Roundup           0
      5             Chlorimuron           0
      6                 Linuron           0
      7                  Pydrin           0
      8                Fusilade           0
      1        33.0         2.0       160.0         0.0        0.50         0.3
   60.0        60.0
      2       530.0         3.0       200.0         0.0        0.65         0.5
   20.0        20.0
      3      2400.0         0.5        10.0         0.0        0.50         0.8
   12.0        12.0
      4       1.0E6         2.5     10000.0         0.0        0.65         0.9
   30.0        30.0
      5       500.0         3.0        20.0         0.0        0.50         0.5
   50.0        50.0
      6        75.0         3.0       863.0         0.0        0.50         0.3
   60.0        60.0
      7        0.10         7.0       1.0E5         0.0         0.4         0.0
   50.0        50.0
      8         2.0         3.0      3000.0         0.0        0.50         0.0
   20.0        20.0
   1100           2
      1        1.69         1.0         0.0        1.00           2
      2        1.13         1.0         0.0        1.00           2
   2051           1
      3        0.03         1.0        0.40        0.60           0
   2166           4
      2        1.13         1.0        0.50        0.50           0
      4        1.69         1.0         0.5        0.50           0
      5        0.02         1.0         0.5        0.50           0
      6        0.20         1.0         0.5        0.50           0
   2213           1
      8        0.22         1.0        0.65        0.35           0
   2244           1
      7        0.15         1.0        0.75        0.25           0
      0
```

(NOTE: 0 on the last line indicates end-of-file)

GLEAMS Pesticide File, Richmond County, Virginia
Rotation 8
No-Till Corn-Cultivate 1x, Plow-Plant Wheat/No-Till Soybeans, Rye Overseed

```
   51000     85365           8           2           0
       1                Aatrex           0
       2                  Dual           0
       3               Harmony           0
       4             Gramoxone           0
       5                Pydrin           0
       6              Fusilade           0
       7                 Lorox           0
       8                Blazer           0
       1      33.0         2.0       160.0         0.0        0.50         0.3
    60.0      60.0
       2     530.0         3.0       200.0         0.0        0.65         0.5
    20.0      20.0
       3    2400.0         0.5        10.0         0.0        0.50         0.8
    12.0      12.0
       4     1.0E6         3.0       1.0E5         0.0        0.40         1.0
  3600.0    3600.0
       5      0.10         7.0       1.0E5         0.0        0.40         0.0
    50.0      50.0
       6       2.0         3.0      3000.0         0.0        0.50         0.0
    20.0      20.0
       7      75.0         3.0       863.0         0.0        0.50         0.3
    60.0      60.0
       8     9.0E5         3.0       139.0         0.0         0.5         1.0
    30.0      30.0
    1105         2
       1      1.69         1.0         0.5        0.50           2
       2      2.25         1.0         0.5        0.50           2
    2051         1
       3      0.03         1.0        0.40        0.60           0
    2166         3
       2      1.69         1.0         0.5        0.50           0
       4      0.53         1.0         0.5        0.50           0
       7      0.56         1.0         0.5        0.50           0
    2186         1
       8      0.42         1.0         0.5        0.50           0
    2213         1
       6      0.22         1.0        0.65        0.35           0
    2244         1
       5      0.15         1.0        0.75        0.25           0
       0
```

(NOTE: 0 on the last line indicates end-of-file)

```
                         GLEAMS Pesticide File, Richmond County, Virginia
                                         Rotation 9
            No-Till Corn-Cultivate 1x, Plow-Plant Wheat/No-Till Soybeans, Rye Overseed
    51000       85365           9           2           0
        1                  Bladex           0
        2                   2,4-D           0
        3                    Dual           0
        4                 Harmony           0
        5               Gramoxone           0
        6                  Pydrin           0
        7                Fusilade           0
        8                   Lorox           0
        9                  Blazer           0
        1       171.0         2.0       168.0         0.0         0.6         0.4
     20.0        20.0
        2       900.0         9.0        74.0         0.0        0.45         0.6
     10.0        10.0
        3       530.0         3.0       200.0         0.0        0.65         0.5
     20.0        20.0
        4      2400.0         0.5        10.0         0.0        0.50         0.8
     12.0        12.0
        5       1.0E6         3.0       1.0E5         0.0         0.4         1.0
   3600.0      3600.0
        6        0.10         7.0       1.0E5         0.0         0.4         0.0
     50.0        50.0
        7         2.0         3.0      3000.0         0.0         0.5         0.0
     20.0        20.0
        8        75.0         3.0       863.0         0.0         0.5         0.3
     60.0        60.0
        9       9.0E5         3.0       139.0         0.0         0.5         1.0
     30.0        30.0
     1105           2
        1        1.80         1.0         0.5        0.50           2
        3        2.25         1.0         0.5        0.50           2
     1166           1
        2        0.56         1.0        0.30        0.70           0
     2051           1
        4        0.03         1.0        0.40        0.60           0
     2166           3
        3        1.69         1.0         0.5        0.50           0
        5        0.53         1.0         0.5        0.50           0
        8        0.56         1.0         0.5        0.50           0
     2186           1
        9        0.42         1.0         0.5         0.5           0
     2213           1
        7        0.22         1.0        0.65        0.35           0
     2244           1
        6        0.15         1.0        0.75        0.25           0
        0
      (NOTE: 0 on the last line indicates end-of-file)
```

GLEAMS Pesticide File, Richmond County, Virginia
Rotation 10
No-Till Corn-Cultivate 1x, Plow-Plant Wheat/No-Till Soybeans, Rye Overseed

```
    51000     85365         8         2         0
        1              Aatrex         0
        2               Lasso         0
        3             Harmony         0
        4           Gramoxone         0
        5              Pydrin         0
        6            Fusilade         0
        7               Lorox         0
        8              Blazer         0
        1      33.0       2.0     160.0       0.0       0.5       0.3
     60.0      60.0
        2     242.0       3.0     190.0       0.0       0.4       0.4
     14.0      14.0
        3    2400.0       0.5      10.0       0.0       0.5       0.8
     12.0      12.0
        4     1.0E6       3.0     1.0E5       0.0       0.4       1.0
   3600.0    3600.0
        5      0.10       7.0     1.0E5       0.0       0.4       0.0
     50.0      50.0
        6       2.0       3.0    3000.0       0.0       0.5       0.0
     20.0      20.0
        7      75.0       3.0     863.0       0.0       0.5       0.3
     60.0      60.0
        8     9.0E5       3.0     139.0       0.0       0.5       1.0
     30.0      30.0
     1105         2
        1      1.69       1.0       0.5      0.50         2
        2      2.25       1.0       0.5      0.50         2
     2051         1
        3      0.03       1.0      0.40      0.60         0
     2166         3
        2      2.25       1.0       0.5      0.50         0
        4      0.53       1.0       0.5      0.50         0
        7      0.56       1.0       0.5      0.50         0
     2186         1
        8      0.42       1.0       0.5      0.50         0
     2213         1
        6      0.22       1.0      0.65      0.35         0
     2244         1
        5      0.15       1.0      0.75      0.25         0
        0
```

(NOTE: 0 on the last line indicates end-of-file)

GLEAMS Pesticide File, Richmond County, Virginia
Rotation 18
No-Till Corn-Cultivate 1x, Plow-Plant Wheat/No-Till Soybeans, Rye Overseed

```
51000     85365         8         2         0
    1               Aatrex        0
    2                 Dual        0
    3              Harmony        0
    4              Roundup        0
    5               Pydrin        0
    6             Fusilade        0
    7                Lorox        0
    8               Blazer        0
    1      33.0       2.0     160.0       0.0       0.5       0.3
 60.0      60.0
    2     530.0       3.0     200.0       0.0      0.65       0.5
 20.0      20.0
    3    2400.0       0.5      10.0       0.0       0.5       0.8
 12.0      12.0
    4     1.0E6       2.5   10000.0       0.0      0.65       0.9
 30.0      30.0
    5      0.10       7.0     1.0E5       0.0       0.4       0.0
 50.0      50.0
    6       2.0       3.0    3000.0       0.0       0.5       0.0
 20.0      20.0
    7      75.0       3.0     863.0       0.0       0.5       0.3
 60.0      60.0
    8     9.0E5       3.0     139.0       0.0       0.5       1.0
 30.0      30.0
 1105         2
    1      1.69       1.0       0.5      0.50         2
    2      2.25       1.0       0.5      0.50         2
 2051         1
    3      0.03       1.0      0.40      0.60         0
 2166         3
    2      1.13       1.0       0.5      0.50         0
    4      1.13       1.0       0.5      0.50         0
    7      0.56       1.0       0.5      0.50         0
 2186         1
    8      0.42       1.0       0.5       0.5         0
 2213         1
    6      0.22       1.0      0.65      0.35         0
 2244         1
    5      0.15       1.0      0.75      0.25         0
    0
```

(NOTE: 0 on the last line indicates end-of-file)

GLEAMS Pesticide File, Richmond County, Virginia

12

```
Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans/Plow-Plant Soybeans, Plow-Plant Wheat/No-Till
Soybeans
   51000        85365           10            4            0
       1                    Aatrex            0
       2                      Dual            0
       3                   Harmony            0
       4                 Gramoxone            0
       5                Chlorimuron           0
       6                   Linuron            0
       7                    Pydrin            0
       8                   Treflan            0
       9                     Lorox            0
      10                   Roundup            0
       1         33.0          2.0        160.0          0.0          0.5          0.3
    60.0         60.0
       2        530.0          3.0        200.0          0.0         0.65          0.5
    20.0         20.0
       3       2400.0          0.5         10.0          0.0          0.5          0.8
    12.0         12.0
       4        1.0E6          3.0        1.0E5          0.0          0.4          1.0
  3600.0       3600.0
       5        500.0          3.0         20.0          0.0          0.5          0.5
    50.0         50.0
       6         75.0          3.0        863.0          0.0          0.5          0.3
    60.0         60.0
       7         0.10          7.0        1.0E5          0.0          0.4          0.0
    50.0         50.0
       8         0.30         20.0       1400.0          0.0          0.4          0.0
    60.0         60.0
       9         75.0          3.0        863.0          0.0          0.5          0.3
    60.0         60.0
      10        1.0E6          2.5      10000.0          0.0         0.65          0.9
    30.0         30.0
    1100            2
       1         1.69          1.0          0.0         1.00            2
       2         2.25          1.0          0.0         1.00            2
    2051            1
       3         0.03          1.0         0.40         0.60            0
    2166            3
       2         1.69          1.0          0.5         0.50            0
       4         0.53          1.0          0.5         0.50            0
       9         0.56          1.0          0.5          0.5            0
    2244            1
       7         0.15          1.0         0.65         0.35            0
    3140            3
       2         1.69          1.0          0.0          1.0            2
       5         0.02          1.0         0.00          1.0            2
       6         0.20          1.0         0.00          1.0            2
    3152            1
      10         1.13          1.0          0.0          1.0            0
    3213            1
       8         0.85          1.0         0.65         0.35            0
    4051            1
       3         0.03          1.0         0.40         0.60            0
    4166            3
       2         1.69          1.0          0.5         0.50            0
       4         0.53          1.0          0.5         0.50            0
       9         0.56          1.0          0.5          0.5            0
    4244            1
       7         0.15          1.0         0.75         0.25            0
       0
```

(NOTE: 0 on the last line indicates end-of-file)

GLEAMS Pesticide File, Richmond County, Virginia
Rotation 12 (continuation)

```
Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans/Plow-Plant Soybeans, Plow-Plant Wheat/No-Till
Soybeans
 51000     85365         2         4         0
     1              Blazer         0
     2            Fusilade         0
     1     9.0E5       3.0     139.0       0.0       0.5       1.0
  30.0      30.0
     2       2.0       3.0    3000.0       0.0       0.5       0.0
  20.0      20.0
  2186         1
     1      0.42       1.0       0.5      0.50         0
  2213         1
     2      0.22       1.0      0.65      0.35         0
  4186         1
     1      0.42       1.0      0.50      0.50         0
  4213         1
     2      0.22       1.0      0.65      0.35         0
     0
```

(NOTE: 0 on the last line indicates end-of-file)

GLEAMS Pesticide File, Richmond County, Virginia
Rotation 13

Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans/Plow-Plant Soybeans, Plow-Plant Wheat/No-Till Soybeans

```
   51000       85365          10           4           0
       1                  Bladex           0
       2                   2,4-D           0
       3                    Dual           0
       4                 Harmony           0
       5               Gramoxone           0
       6             Chlorimuron           0
       7                 Linuron           0
       8                  Pydrin           0
       9                 Treflan           0
      10                   Lorox           0
       1       171.0         2.0       168.0         0.0         0.6         0.4
    20.0        20.0
       2       900.0         9.0        74.0         0.0        0.45         0.6
    10.0        10.0
       3       530.0         3.0       200.0         0.0        0.65         0.5
    20.0        20.0
       4      2400.0         0.5        10.0         0.0         0.5         0.8
    12.0        12.0
       5       1.0E6         3.0       1.0E5         0.0         0.4         1.0
  3600.0      3600.0
       6       500.0         3.0        20.0         0.0         0.5         0.5
    50.0        50.0
       7        75.0         3.0       863.0         0.0         0.5         0.3
    60.0        60.0
       8        0.10         7.0       1.0E5         0.0         0.4         0.0
    50.0        50.0
       9        0.30        20.0      1400.0         0.0         0.4         0.0
    60.0        60.0
      10        75.0         3.0       863.0         0.0         0.5         0.3
    60.0        60.0
    1100           2
       1        1.80         1.0         0.0        1.00           2
       3        2.25         1.0         0.0        1.00           2
    1130           1
       2        0.56         1.0         0.0        1.00           0
    2051           1
       4        0.03         1.0        0.40        0.60           0
    2166           3
       3        1.69         1.0         0.5        0.50           0
       5        0.53         1.0         0.5        0.50           0
      10        0.56         1.0         0.5        0.50           0
    2244           1
       8        0.15         1.0        0.75        0.25           0
    3140           3
       3        1.69         1.0         0.0         1.0           2
       6        0.02         1.0         0.0         1.0           2
       7        0.20         1.0         0.0         1.0           2
    3213           1
       9        0.85         1.0        0.65        0.35           0
    4051           1
       4        0.03         1.0        0.40        0.60           0
    4166           3
       3        1.69         1.0         0.5        0.50           0
       5        0.53         1.0         0.5        0.50           0
      10        0.56         1.0         0.5        0.50           0
    4244           1
       8        0.15         1.0        0.75        0.25           0
       0
```

(NOTE: 0 on the last line indicates end-of-file)

GLEAMS Pesticide File, Richmond County, Virginia

Rotation 13 (continuation)

Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans/Plow-Plant Soybeans, Plow-Plant Wheat/No-Till Soybeans

```
 51000       85365           3           4           0
     1                 Roundup           0
     2                  Blazer           0
     3                Fusilade           0
     1       1.0E6         2.5     10000.0         0.0        0.65         0.9
  30.0        30.0
     2       9.0E5         3.0       139.0         0.0         0.5         0.5
  30.0        30.0
     3         2.0         3.0      3000.0         0.0         0.5         0.0
  20.0        20.0
  2186           1
     2        0.42         1.0         0.5        0.50           0
  2213           1
     3        0.22         1.0        0.65        0.35           0
  3152           1
     1        1.13         1.0        0.00        1.00           0
  4186           1
     2        0.42         1.0        0.50        0.50           0
  4213           1
     3        0.22         1.0        0.65        0.35           0
     0
```

(NOTE: 0 on the last line indicates end-of-file)

```
               GLEAMS Pesticide File, Richmond County, Virginia
                                 Rotation 14
Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans/Plow-Plant Soybeans, Plow-Plant Wheat/No-Till
Soybeans
  51000     85365          10           4         0
      1                Aatrex           0
      2                 Lasso           0
      3               Harmony           0
      4             Gramoxone           0
      5           Chlorimuron           0
      6               Linuron           0
      7                Pydrin           0
      8               Treflan           0
      9                 Lorox           0
     10               Roundup           0
      1      33.0         3.0       160.0       0.0       0.5       0.3
   60.0      60.0
      2     242.0         3.0       190.0       0.0       0.4       0.4
   14.0      14.0
      3    2400.0         0.5        10.0       0.0       0.5       0.8
   12.0      12.0
      4     1.0E6         3.0       1.0E5       0.0       0.4       1.0
 3600.0    3600.0
      5     500.0         3.0        20.0       0.0       0.5       0.5
   50.0      50.0
      6      75.0         3.0       863.0       0.0       0.5       0.3
   60.0      60.0
      7      0.10         7.0       1.0E5       0.0       0.4       0.0
   50.0      50.0
      8      0.30        20.0      1400.0       0.0       0.4       0.0
   60.0      60.0
      9      75.0         3.0       863.0       0.0       0.5       0.3
   60.0      60.0
     10     1.0E6         2.5     10000.0       0.0      0.65       0.9
   30.0      30.0
   1100         2
      1      1.69         1.0         0.0      1.00         2
      2      2.25         1.0         0.0      1.00         2
   2051         1
      3      0.03         1.0        0.40      0.60         0
   2166         3
      2      2.25         1.0         0.5      0.50         0
      4      0.53         1.0         0.5      0.50         0
      9      0.56         1.0         0.5       0.5         0
   2244         1
      7      0.15         1.0        0.75      0.25         0
   3140         3
      2      2.25         1.0         0.0       1.0         2
      5      0.02         1.0        0.00      1.00         2
      6      0.20         1.0        0.00      1.00         2
   3152         1
     10      1.13         1.0         0.0       1.0         0
   3213         1
      8      0.85         1.0        0.65      0.35         0
   4051         1
      3      0.03         1.0        0.40      0.60         0
   4166         3
      2      2.25         1.0         0.5      0.50         0
      4      0.53         1.0         0.5      0.50         0
      9      0.56         1.0         0.5       0.5         0
   4244         1
      7      0.15         1.0        0.75      0.25         0
      0
```

(NOTE: 0 on the last line indicates end-of-file)

GLEAMS Pesticide File, Richmond County, Virginia
Rotation 14 (continuation)

Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans/Plow-Plant Soybeans, Plow-Plant Wheat/No-Till Soybeans

```
 51000       85365            2            4           0
     1                   Blazer            0
     2                 Fusilade            0
     1        9.0E5         3.0        139.0         0.0         0.5         1.0
  30.0         30.0
     2          2.0         3.0       3000.0         0.0         0.5         0.0
  20.0         20.0
  2186            1
     1         0.42         1.0          0.5        0.50           0
  2213            1
     2         0.22         1.0         0.65        0.35           0
  4186            1
     1         0.42         1.0         0.50        0.50           0
  4213            1
     2         0.22         1.0         0.65        0.35           0
     0
```

(NOTE: 0 on the last line indicates end-of-file)

GLEAMS Pesticide File, Richmond County, Virginia
Rotation 19

```
Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans/Plow-Plant Soybeans, Plow-Plant Wheat/No-Till
Soybeans
   51000       85365           9           4           0
       1                  Aatrex           0
       2                    Dual           0
       3                 Harmony           0
       4                 Roundup           0
       5             Chlorimuron           0
       6                 Linuron           0
       7                  Pydrin           0
       8                 Treflan           0
       9                   Lorox           0
       1        33.0         2.0       160.0         0.0         0.5         0.3
    60.0        60.0
       2       530.0         3.0       200.0         0.0        0.65         0.5
    20.0        20.0
       3      2400.0         0.5        10.0         0.0         0.5         0.8
    12.0        12.0
       4       1.0E6         2.5     10000.0         0.0        0.65         0.9
    30.0        30.0
       5       500.0         3.0        20.0         0.0         0.5         0.5
    50.0        50.0
       6        75.0         3.0       863.0         0.0         0.5         0.3
    60.0        60.0
       7        0.10         7.0       1.0E5         0.0         0.4         0.0
    50.0        50.0
       8        0.30        20.0      1400.0         0.0         0.4         0.0
    60.0        60.0
       9        75.0         3.0       863.0         0.0         0.5         0.3
    60.0        60.0
    1100           2
       1        1.69         1.0         0.0        1.00           2
       2        1.13         1.0         0.0        1.00           2
    2051           1
       3        0.03         1.0        0.40        0.60           0
    2166           3
       2        1.13         1.0         0.5        0.50           0
       4        1.13         1.0         0.5        0.50           0
       9        0.56         1.0         0.5         0.5           0
    2244           1
       7        0.15         1.0        0.75        0.25           0
    3140           3
       2        1.69         1.0         0.0         1.0           2
       5        0.02         1.0        0.00        1.00           2
       6        0.20         1.0        0.00        1.00           2
    3152           1
       4        1.13         1.0         0.0         1.0           0
    3213           1
       8        0.85         1.0        0.65        0.35           0
    4051           1
       3        0.03         1.0        0.40        0.60           0
    4166           3
       2        1.13         1.0         0.5        0.50           0
       4        1.13         1.0         0.5        0.50           0
       9        0.56         1.0         0.5         0.5           0
    4244           1
       7        0.15         1.0        0.75        0.25           0
       0
```

(NOTE: 0 on the last line indicates end-of-file)

GLEAMS Pesticide File, Richmond County, Virginia
Rotation 19 (continuation)

Plow-Plant Corn, Plow-Plant Wheat/No-Till Soybeans/Plow-Plant Soybeans, Plow-Plant Wheat/No-Till Soybeans

```
 51000      85365          2          4          0
     1                Blazer          0
     2              Fusilade          0
     1      9.0E5        3.0      139.0        0.0        0.5        1.0
  30.0       30.0
     2        2.0        3.0     3000.0        0.0        0.5        0.0
  20.0       20.0
  2186          1
     1       0.42        1.0        0.5       0.50          0
  2213          1
     2       0.22        1.0       0.65       0.35          0
  4186          1
     1       0.42        1.0       0.50       0.50          0
  4213          1
     2       0.22        1.0       0.65       0.35          0
     0
```

(NOTE: 0 on the last line indicates end-of-file)

GLEAMS Pesticide File, Richmond County, Virginia
Rotation 15
Disk-Plant Corn, Plow-Plant Wheat/No-Till Soybeans, Rye & Clover Overseed

```
   51000       85365           8           2           0
       1                  Aatrex           0
       2                    Dual           0
       3                 Harmony           0
       4               Gramoxone           0
       5                  Pydrin           0
       6                   Lorox           0
       7                  Blazer           0
       8                Fusilade           0
       1        33.0         3.0       160.0         0.0         0.5         0.3
    60.0        60.0
       2       530.0         3.0       200.0         0.0        0.65         0.5
    20.0        20.0
       3      2400.0         0.5        10.0         0.0         0.5         0.8
    12.0        12.0
       4       1.0E6         3.0       1.0E5         0.0         0.4         1.0
  3600.0      3600.0
       5        0.10         7.0       1.0E5         0.0         0.4         0.0
    50.0        50.0
       6        75.0         3.0       863.0         0.0         0.5         0.3
    60.0        60.0
       7       9.0E5         3.0       139.0         0.0         0.5         1.0
    30.0        30.0
       8         2.0         3.0      3000.0         0.0         0.5         0.0
    20.0        20.0
    1115           2
       1        1.69         1.0         0.2        0.80           2
       2        1.13         1.0         0.2        0.80           2
    2051           1
       3        0.03         1.0        0.40        0.60           0
    2166           3
       2        1.69         1.0         0.5        0.50           0
       4        0.53         1.0         0.5        0.50           0
       6        0.56         1.0         0.5        0.50           0
    2186           1
       7        0.42         1.0         0.5         0.5           0
    2213           1
       8        0.22         1.0        0.65        0.35           0
    2244           1
       5        0.15         1.0        0.75        0.25           0
       0
```

(NOTE: 0 on the last line indicates end-of-file)

VITA

Born:

Peter Edward Davis, Radford, Virginia, August 31, 1965

Parents:

William E. and Mary Jane Beurket

Education:

North Carolina State University, Raleigh, North Carolina.
B.S. in Agricultural Engineering, May, 1988.

Professional Experience:

Project Assistant. NCSU Water Quality Group, Raleigh, North Carolina, 1988

Graduate Research Assistant, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. Agricultural Engineering Department

Professional Societies:

American Society of Agricultural Engineers
Soil and Water Conservation Society

Honorary:

Alpha Epsilon

Peter E. Davis