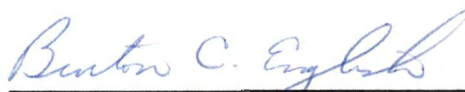


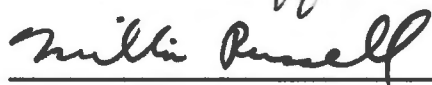
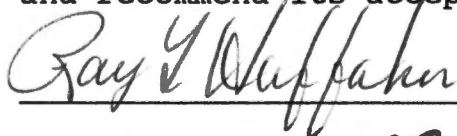
To the Graduate Council:

I am submitting herewith a dissertation written by Gary V. Cole entitled "An Economic Optimal Control Evaluation of Achieving/Maintaining Groundwater Quality Contaminated From Nonpoint Agricultural Sources." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a Major in Agricultural Economics.



Burton C. English, Major Professor

We have read this dissertation
and recommend its acceptance:



Accepted for the Council:



Vice Provost
and Dean of The Graduate School

**AN ECONOMIC OPTIMAL CONTROL EVALUATION OF
ACHIEVING/MAINTAINING GROUNDWATER QUALITY CONTAMINATED FROM
NONPOINT AGRICULTURAL SOURCES**

**A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville**

GARY V. COLE

May, 1991

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ABSTRACT

Agriculture has been identified as a contributor to ground water contamination. The controversy which relates to the agricultural chemical contamination of ground water is between consumers, demanding clean water and agricultural producers, who want to maintain the right to employ the production process (including the use of chemicals, rotation and tillage practices) of their choosing. This study developed a methodology which may be used to dynamically examine the producer/consumer conflict related to nonpoint agricultural chemical contamination of a regional ground water resource. Available means of obtaining acceptable ground water quality included pollution prevention techniques (restricting agricultural chemical inputs or changing crop production practices) and end of pipe abatement methods.

Objectives were to select an agricultural chemical contaminant, estimate the regional agricultural costs associated with restricting the use of the selected chemical, estimate the economic costs associated with point of use ground water contaminant removal and determine the least cost method for obtaining water quality.

The nitrate chemical derived from nitrogen fertilizer was selected as the contaminate. A three county study area was identified in the Northwest part of Tennessee. The different modeling techniques used were categorized as dynamic optimal

control, prevention, and point of use nitrate removal. A plant growth and leaching model, a budget generator, a linear programming, and optimal control model were used in the analysis.

Crop rotations remained in a corn-soybean-wheat/soybean pattern as nitrogen fertilizer restrictions were imposed. Agricultural net revenue for the region did not decrease significantly as nitrogen fertilizer was restricted, partly due to the small yield responses generated by the plant growth and leaching model. Soybean fixation of nitrogen contributed to the stability in yields generated by the plant growth and leaching model. The dynamic results indicated that agriculture was financially responsible for obtaining clean point of use water only when the cost of filtering increased substantially or the population in the region was much larger than currently existed.

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CHAPTER I

INTRODUCTION

Background

Ground water quality, historically, has not received substantial attention from the public. The relative quality of ground water, other than clarity, has not been a major concern among users. The majority of people in the United States, as recent as 1974, considered drinking water to be of generally good quality (Pojasek, 1977 citing Chemical Engineering News, 1974).

Infiltration of chemicals and movement of ground water¹ can be a slow process and detection of ground water contaminants was delayed. However, "Discoveries of chemical residuals in ground water during the late 1970's and early 1980's dispelled the commonly held view that ground water was protected from agricultural chemicals by impervious layers of rock, soil, and clay and their chemical degradation" (Crutchfield, 1989, p. 3). As a result, by the 1980's ground water quality became an environmental focus area. Limited available information regarding the extent of contamination and the associated health effects from ingesting contaminated water has contributed to the apprehension society has about

¹ Ground water is "water that occurs beneath the water table in solid and geologic formations that are fully saturated" (Canter, Knox, and Fairchild, 1987).

the seriousness of ground water pollution. The public currently perceives the chemical contamination of water supplies as dangerous. The result is that potable water quality has become a concern of society (Batie, 1988).

The importance of ground water as a fresh water resource is undisputed. Ground water provides approximately 50 percent of the U.S. population with drinking water and an estimated 40 percent of all irrigation water (SRA Technologies, Inc., 1986). Ground water accounts for 95 percent of the fresh water reserves in the United States (Anderson, Opaluch, and Sullivan, 1985). Use of ground water in Tennessee is similar to national levels, with 51 percent of the population depending on ground water for human consumption. Excluding thermoelectric use, 21 percent of water withdrawal in Tennessee is from ground water sources accounting for 250 million gallons per day for public and rural use (Tennessee Ground Water Policy Dialogue Group, 1987).

Contaminants of ground water may be classified as originating from point or nonpoint sources. Point source pollution enters the environment at a discrete identifiable location allowing direct measurement or quantification of the pollutant. Examples of point source pollution are industrial spills, industrial or sewage treatment plants, and waste from farm buildings or solid waste disposal sites. Nonpoint pollution enters the environment from diffuse sources, generally cannot be monitored at the point of origin, and the

exact source is difficult to identify (Novotny and Chester, 1981).

Agriculture, defined as farm producing units, have been identified as contributors to ground water contamination (Agriculture, Resource and Environmental Policy Research Consortium, 1989). The agricultural and technological revolution, which included development and use of fertilizer, pesticides, and other chemicals, resulted in substantial productivity gains. However, the use of agricultural chemicals imposed negative externalities on the environment. Pesticides, nutrients, and irrigation driven salt water migration have been identified as nonpoint agricultural contamination sources of ground water. Excluding confined livestock operations and irrigation, ground water contamination from agricultural sources may be defined as a nonpoint pollution source.

Hallberg (1986d) describes the events which resulted in the agricultural contamination of ground water supplies. Agriculture during the last several decades has been confronted with political and economic pressures which promoted production. Agricultural producers, in response, adjusted production practices away from crop rotation toward continuous row cropping, toward using fertilizers, from hoes to using herbicide. Labor and fuel costs were traded for chemical use to obtain the most efficient production methods possible. The use of chemicals has been extremely profitable

for farm operators and has been a major contributor to the productivity of the agricultural industry in the United States; this is particularly true for the use of fertilizer chemicals. Farm operators, confronted with short term cash flow problems rely on chemicals as a form of insurance, guaranteeing cash crop income. Agriculture "...has become another victim of chemical dependency" (Hallberg, 1986d, p. 357).

Economists encouraged production based on marginal economics and excluded the potential negative externalities which agricultural chemicals may have imposed on the ground water environment. There was no incentive to include the potential externality cost in production economic analysis since the contamination potential was uncertain. The property rights of ground water, as a result, may have been unknowingly assigned to the producers. Agriculture may have been using ground water as a chemical waste disposal area.

A debate exists as to the extent of the contributions agriculture has been making toward contaminating ground water. Research studies, however, provide results which indicate that agriculture has been responsible for at least some of the contaminated rural ground water. "In most technical articles the debate is no longer about whether or not agricultural activities contaminate ground water...Current discussion focus on where, when, why, the seriousness of the problem and what can be done about it" (Hallberg, 1986d, p. 357).

A schematic diagram of a regional ground water contamination episode from agricultural chemicals is illustrated in Figure 1. Agricultural sources of contamination include pesticides and nutrients. The soil area below the surface is categorized into three hydrologic zones: the root, vadose and ground water zone (Singh and Sekhon, 1978/79). The root and vadose zone are areas where chemical leaching occurs. Factors affecting the leaching process include amount of chemical applied, tillage and cropping practices, weather (precipitation), soil types, hydrologic characteristics, and physical properties of the chemical.

The potential for aquifer² contamination increases with application of agricultural chemicals to field crops (Crowder and Young, 1988; and USDA, 1970). Pesticides are a potential contributor with per acre application tripling since 1964 (Nielson and Lee, 1987). An estimated 280 million acres are treated annually with some form of pesticide, with corn, cotton, soybeans, and wheat accounting for 85 percent of all herbicide and 70 percent of all insecticide used (Office of Technology and Assessment, 1984). The major nutrient source of ground water contamination is the use of inorganic nitrogen

² An aquifer is defined as geological formations having adequate permeability (porosity and fractures) to transmit and yield water. Two types of aquifers exist, confined and unconfined. An unconfined aquifer (sometimes called a water table aquifer) contains water under atmospheric pressure, and the water level may rise and fall according to the recharge rate and volume stored. A confined aquifer (sometimes called an artisan aquifer) is confined from the top and bottom by impermeable materials (Canter, Knox, and Fairchild, 1987).

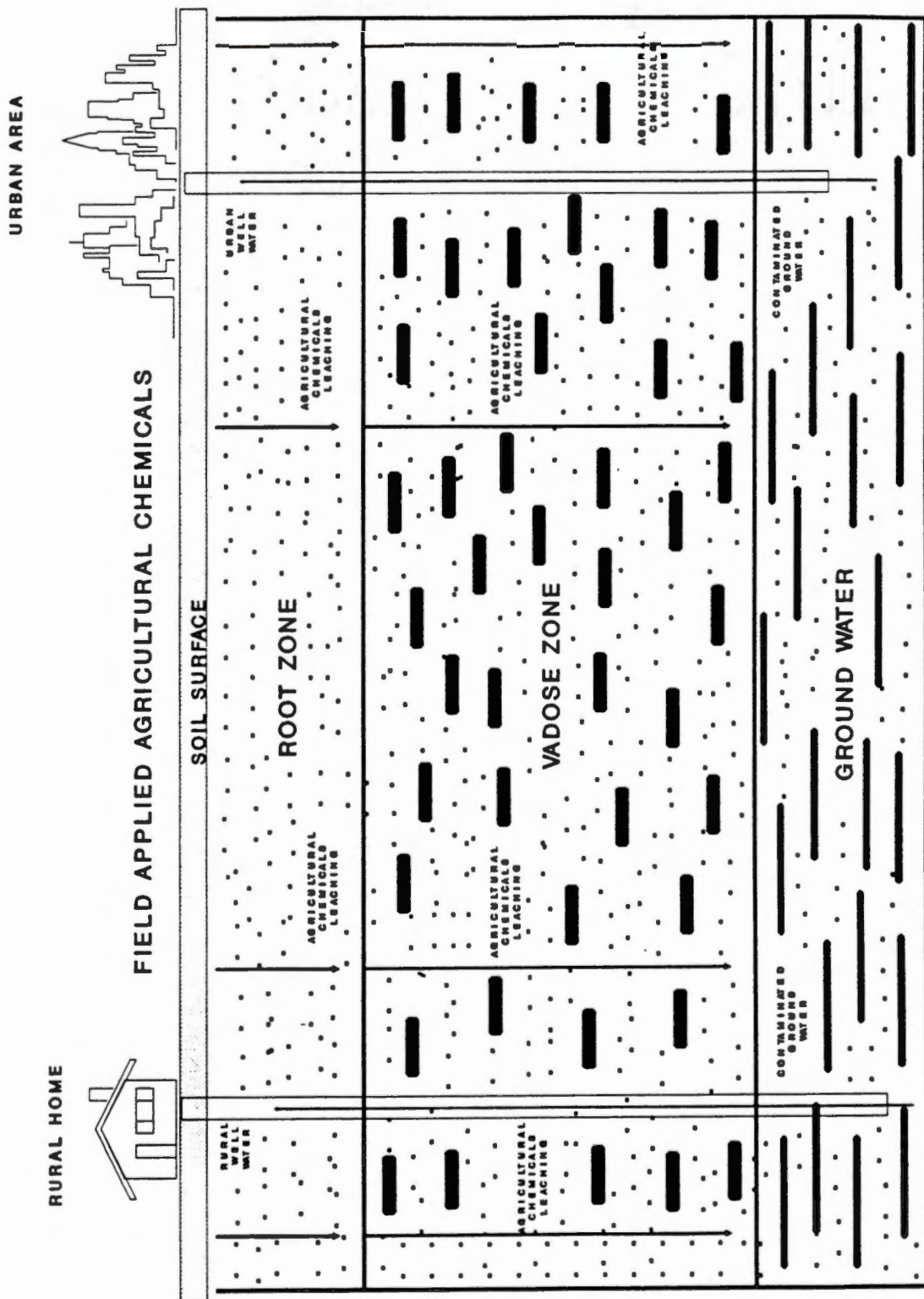


Figure 1. Agricultural Chemical Contamination of Ground Water.

fertilizers and livestock manure. Inorganic nitrogen fertilizer increased fourfold between 1960 and 1980 (Nielson and Lee, 1987).

Nonpoint agricultural ground water contamination control methods are limited. Prevention at the pollution source or clean up measures at point of use, for the most part, exhaust nonpoint pollution corrective measures (Figure 2). The clean up approach relies on technology to facilitate and remove pollution from the ground water resource while imposing no restrictions on the polluting source. Various types of point of use chemical removal systems may be used to remove pollutants from the water supply. Prevention is directed at the pollution source and imposes restrictive regulations prohibiting the pollutant from being generated (Amemiya, 1982). The preventive option may include restricting use of a chemical, and utilizing different tillage (conservation vs. conventional) or cropping practices.

The controversy which relates to the agricultural chemical contamination of ground water is between consumers demanding clean water and agricultural producers who want to maintain the right to employ the production process (including the use of chemicals, rotation and tillage practices) of their choosing. Economic analysis provides a guide to society and policy makers in addressing the producer-consumer conflict between agricultural productivity and the associated decrease in ground water quality. A review of literature indicated

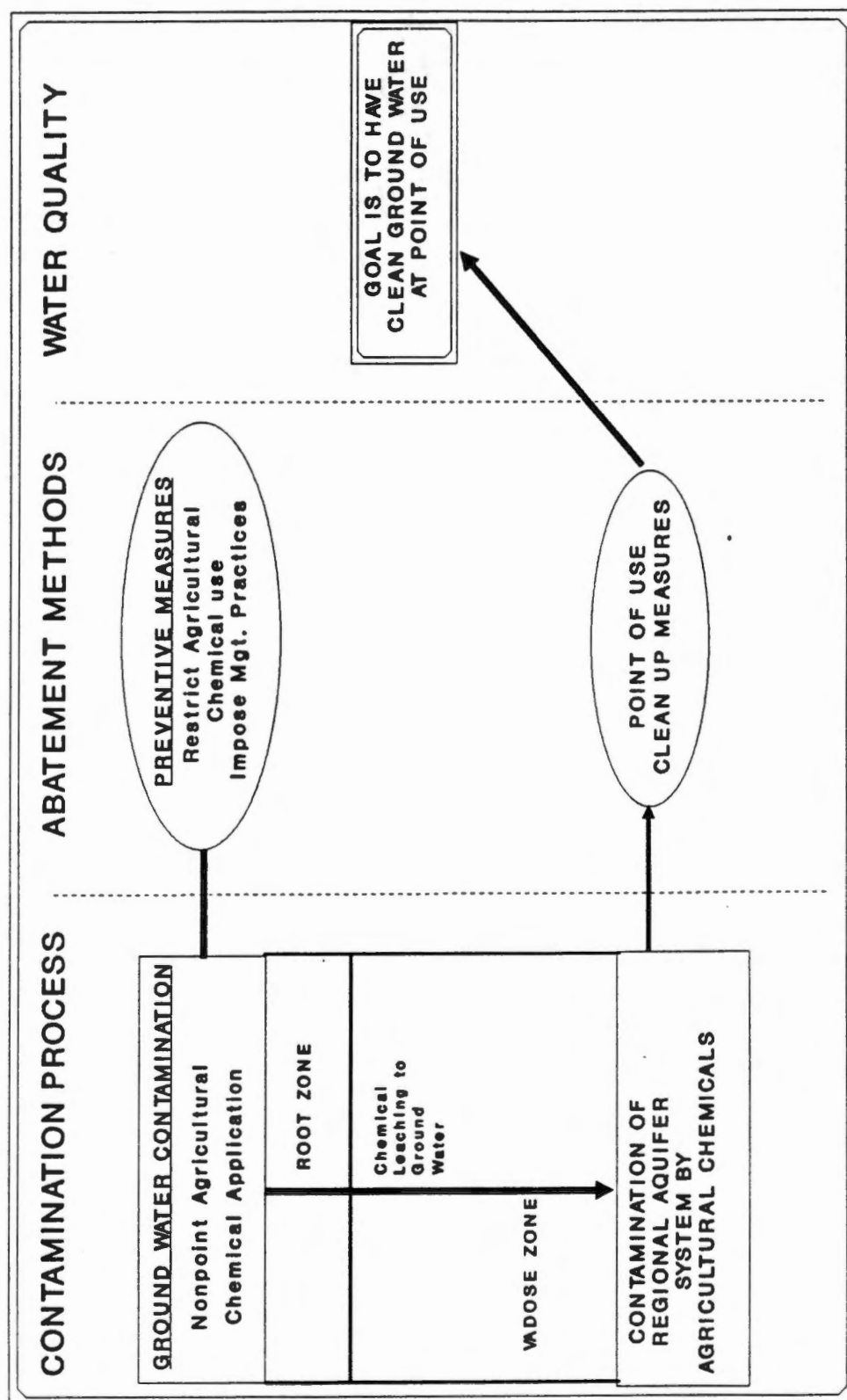


Figure 2. Contamination of Ground Water From Agricultural Chemicals and Possible Abatement Strategies.

that little information was available to assist policy makers in developing ground water policies, other than prevention strategies, for contamination by nonpoint agricultural sources. Prevention strategies are currently preferred by policy makers. However, such strategies may not always be the most cost efficient.

This study developed a methodology which may be used to examine the producer-consumer conflict related to nonpoint agricultural chemical contamination of a regional ground water resource. The objective for the contaminated region was to obtain Environmental Protection Agency (EPA) point of use ground water standards for a contaminant. Available means for obtaining acceptable ground water quality included agricultural chemical input restrictions and changes in crop production practices (to maximize the cleansing effect of the natural process), or installation and utilization of point of use water cleansing systems to remove the contaminant. Determining the optimal strategy for a region, or a combination of strategies to attain ground water quality, utilizing the minimum amount of economic resources was the focus of the study. Special emphasis was placed on the dynamic economic conflict between the agricultural producer, who contaminates ground water, and the consumer who demands clean water.

Need For The Study

The public has perceived agriculture as a non polluting industry, stewards of the environment, and accepted the increased productivity associated with chemical use. Agriculture has been allowed special policy privileges as public attitude has been directed toward how policies would benefit agriculture (Batie, 1986). The attitude of Society has been changing, however, and agriculture is being viewed as any other polluting industry. "In the past, many resource policies were constrained by a concern for how well they served the interests of agriculture...Increasingly the question is now asked: How do agricultural programs and policies conform to goals of environmental protection and enhancement" (Batie, 1984, pg. 814).

Recent farm policy debate has focused on agriculture as a source of ground water contamination. Initiatives are shifting from those of maintaining agricultural productivity, controlling surplus production, and maintaining farm income, to concerns of environmental preservation (Crutchfield, 1989). The United States Department of Agriculture has made the chemical contamination of surface and ground water from nonpoint agricultural sources a priority item (USDA, 1989). Benbrook (1988) suggests that nitrogen fertilizer contamination will be a special matter of priority. The need to provide economic analysis on minimizing the cost of

achieving ground water quality increases as farm policy concerns shift toward agricultural contamination of the environment.

Society can obtain clean water only with the sacrifice of other resources. Water quality management is a problem in the allocation of scarce resources (Upton, 1968). Current economic literature has not provided dynamic economic information related to the producer-consumer conflict from using resources efficiently to obtain ground water quality. Economic research on nonpoint agricultural chemical pollution has primarily focused on national prevention policies including: Well Head Protection, Well Busters, and CRP Expansion Programs (Crutchfield, 1989). The general attitude of policy makers has been that prevention is the preferred method of addressing the nonpoint source contamination of ground water.

Aquifers which are vulnerable to the contamination of agricultural chemicals are regional (Nielson and Lee, 1987). Economic analysis of the regional contamination of ground water may indicate that the most economically efficient strategy, for some regions, is complete protection of the aquifer from contamination. The most economically efficient strategy for another region may be little or no protection of the aquifer but treatment of the contaminated water at point of use.

The economic problems of nonpoint agricultural

contamination of ground water are, as are most economic problems, dynamic. Optimal water quality management involves a multistage decision process (Worthington, Burt and Brustkeven, 1985). Contamination of an aquifer from agricultural chemicals are applied to the field surfaces and not directly to a ground water aquifer. Weather, soil structure, and chemical characteristics influence contamination of the aquifer. Chemical leaching may be either a quick or slow process.

Previous economic research related to ground water contamination and abatement strategies have focused primarily on static analysis. Lack of dynamic economic information provides a void for policy makers in their attempt to determine the appropriate policy options to utilize. Physical scientist also need to know the types of information required by economist for conducting for economic analysis of ground water abatement strategies. There exists a need to provide dynamic economic information on the optimal abatement strategies (prevention, clean up, or a combination), for achieving regional water quality from ground water sources which have been contaminated by agricultural chemicals.

Objectives

This study examined the dynamic economic conflict between agricultural producers, who contaminates ground water and the

consumer, who is demanding clean point of use water. Economic analysis of preventive or clean up strategies were conducted to determine the least cost means available to address the regional nonpoint contamination of ground water from agricultural sources. The primary objective of the study was to develop a methodology that would allow dynamic regional economic analysis of obtaining improved ground water quality which has been contaminated from non point agricultural sources. The specific objectives were:

1. select an agricultural chemical which poses a threat to ground water contamination;
2. estimate the regional agricultural costs associated with restricting the use of the selected chemical;
3. estimate the economic costs associated with point of use ground water contaminant removal; and
4. determine the least cost method available for obtaining point of use water quality goals from ground water which has been contaminated from nonpoint agricultural sources.

CHAPTER II

GROUND WATER CONTAMINANT

Contaminant Selection

Production of field crops utilize numerous chemical inputs including insecticides, herbicides, and plant nutrients (fertilizers), each providing the potential for ground water contamination (Stewart, 1987; and Hallberg, 1986d). During the last several decades field applied nitrogen fertilizers have been an area of public concern as the concentration level of nitrates in drinking water has been increasing (Hallberg, 1986d; Organisation for Economic Co-operation and Development, 1986; and Pojasek, 1977). Nitrate contamination may occur from several sources including: precipitation, soil and rock formations, agricultural use of field applied nitrogen fertilizer, urban waste disposal, livestock manure, crop residues, naturally occurring deposits of nitrate containing materials, and decomposing animal or plant tissue (Organisation for Economic Co-operation and Development, 1986; World Health Organization, 1984; National Research Council, 1978; and Pojasek, 1977).

Although uncertainty exists as to the source and fate of the nitrate chemical in the environment, the agricultural production sector has been identified as a major contributor

to the nitrate contamination of ground water. "...research world wide over the past 10 years has shown that the most extensive source of nitrates delivered to ground water and surface water is agriculture" (Hallberg, 1986d, p. 358). Agricultural production of grain commodities rely heavily on nitrogen fertilizer as a plant nutrient supplement for increased yield. "Nitrogen is a dominant nutrient in plant growth because nitrate availability affects crop growth immediately" (Organisation for Economic Co-operation and Development, 1986, p. 26). Corn production requires the most nutrient supplement of the cash grain crops (National Research Council, 1978). The importance of nitrogen as a plant nutrient supplement for increased productivity has been researched and documented (National Research Council, 1978 citing Viets, 1965).

The importance of nitrogen as a crop nutrient supplement may be illustrated through the economic impacts which occur if restrictions on use are imposed. Hypothetically, a policy of restricting fertilizer use would result in significant financial costs to the producer through lower yields and in higher food prices to consumers. Taylor and Frohberg (1977), attempted to estimate the partial welfare effects of several public policies on the agricultural industry. Included were two nitrogen fertilizer restriction policies which allowed no more than 100 lbs. per acre and 50 lbs. per acre of nitrogen fertilizer to be applied to crop production in the midwest

Corn Belt states. The fertilizer restrictions included nitrogen added from manure and legumes, and field applied chemical nitrogen. A linear programming model was used to analyze the policy impacts. Restricting nitrogen fertilizer use to 100 lbs. per acre resulted in an annual consumer surplus reduction of \$231 million, while for a nitrogen reduction of 50 lbs. per acre consumer surplus decreased by \$3,325 million. Producer surplus increased by \$21 million for the 100 lb. restriction level and \$2,036 million for the 50 lb. restriction level. The consumer and producer surplus were partial in that environmental benefits of enforcement costs were not captured in the analysis.

There exists a concern in society about the use of nitrogen fertilizer and the nitrate contamination of ground water supplies (Nielsen and Lee, 1987). The economic importance of nitrogen fertilizer as a crop production input supports the need for economic research on policies which may alter the use of agricultural production practices. The chemical focused on in this study was field applied chemical fertilizer and the associated nitrate contamination of ground water.

Health Effects

The nitrate chemical, when transformed to nitrite, is most hazardous to humans and mammals. The non-transformed

nitrate chemical is not extremely hazardous to humans unless exposure is excessive (Lee, 1970 citing Burden, 1961). The majority of negative human and mammal health effects which occur from nitrates are a result of the easy conversion of nitrates to nitrites in the body (World Health Organization, 1984; United States Environmental Protection Agency, 1983; and Wolff and Wasserman, 1972). Formation of nitrites in the human body may be hazardous for two reasons:

1. Nitrites can oxidize haemoglobin to methaemoglobin, a pigment that is incapable of acting as a carrier of oxygen.
2. Under certain conditions, nitrites may react in the human body with secondary and tertiary amines commonly derived from food and other sources to form nitrosamine, some of which are considered to be carcinogenic (World Health Organization, 1984, p. 132 citing World Health Organization, 1978).

Nitrate contamination of ground water has the potential to cause several health problems including birth defects, cancers, nervous system impairments, and methemoglobinemia (Council for Agricultural Science and Technology, 1985). The most common illness resulting from nitrate consumption is methemoglobinemia in infants (SRA Technologies, Inc., 1986; Council for Agricultural Science and Technology, 1985; Kerr, 1979; and the National Research Council, 1978). Issues surrounding nitrate consumption first surfaced in 1945 with reported incidence of nitrate related infant methemoglobinemia in rural areas (Pojasek, 1977). Contaminated ground water supplies were determined to be the primary medium of nitrate

exposure for the methemoglobinemia illnesses. The true extent of nitrate related illness in infants is not known. Reporting of methemoglobinemia is not required by most state agencies. However, "approximately 90 papers reviewed by one author identified 178 cases of infant methemoglobinemia including 39 fatalities that appeared related to the intake of nitrates from drinking water" (Pojasek, 1977, p. 275 citing Walton, 1951).

Although there are medical cures for methemoglobinemia, the potential health problem continues to exist in the United States. The most recent health incidence related to nitrates involved the death of a two month old South Dakota girl in 1981. Well water on the farm contained 152 parts per million of nitrate, exceeding the accepted 45 parts per million quality standard (Busch and Meyers, 1982).

The potential for additional illnesses due to nitrate contamination exist as nitrogen fertilizer continues to be applied to soils and with more nitrate contamination of the ground water supplies being discovered. Nitrate contamination of ground water which exceeds the EPA standard of 10 mg/l (milligrams per liter) or 45 ppm (parts per million) has been recorded in several states including California, New York, Kentucky, Missouri, North Carolina, Texas, Wisconsin, Georgia, Iowa, Minnesota, Kansas, Oklahoma and Illinois (Clifford and Weber, 1978). The large areas in the United States which are associated with nitrate contamination increase the importance

of developing methods to identify the most economically feasible methods of correcting the problem.

Nitrogen Nitrate Chemical Characteristics and Hydrology

Nitrogen can be found in plants, animals, humans, soils, surface water, ground water, various minerals and in the atmosphere (Council for Agricultural Science and Technology, 1985). "Nitrogen exists in soils primarily as organically bound nitrogen in the form of humus and inorganic nitrogen present as ammonium (NH_4^+) and Nitrate (NO_3^-)" (Johnson, G. V., 1987, p. 128). Nitrogen in organic form comprises about 99 percent of the total available in the soils. Plants, however, can not absorb nitrogen which is in the organic form. Organic nitrogen is converted to inorganic form by microorganisms. Ammonium is the first inorganic form resulting from the transformation. The nitrate chemical is derived from ammonium through another microbiological process, denitrification. Mineral nitrogen for plant nutrient supplement, which is in the form of nitrates, can directly be absorbed by plants. When the soil has sufficient mineral nitrogen to satisfy crop and microbial needs, that which is in excess is in the form of nitrates, a chemical which is very soluble in water (Harlburt, 1988; Johnson, G. V., 1987; Alderfer, and Lovelace, 1977; Singh and Sekhon, 1978/79; and World Health Organization, 1984). Nitrates are the most prevalent form of water soluble

nitrogen in the soil, are subject to water movement and have a high potential for leaching to ground water aquifers.

Ammonium chemical fertilizer is also easily absorbed by plants but does not move easily through the soil and thus has a low potential for leaching to ground water. Ammonium is easily converted to nitrate, however, and contributes to the contamination of ground water (Tennessee Department of Health and Environment, 1986; and Kerr, 1977).

Farm operators apply nitrogen for specific yield goals. Excess nitrogen-nitrates are available for leaching to the ground water aquifer if agronomic, weather or other conditions do not match the yield goal. "While the total fertilizer nitrogen uptake by corn may be around 50 percent, the residue typically remains in the field. The fertilizer nitrogen actually removed in harvested grain is typically more in the range of 35 percent or less, particularly for continuous corn" (Hallberg, 1986d citing Hallberg, 1986c; Hallberg, 1986b; and Keeney, 1986a). As a result, approximately 60 to 70 percent of chemical nitrogen applied to the fields has the potential to leach to ground water supplies.

Soil types and profile, land surface conditions (crop residue), chemical characteristics of the contaminant have the potential to affect the hydrology and leaching potential of nitrates to ground water. Tillage and crop rotation practices employed by the farm operator may have an affect on the volume of nitrate which is leached to the ground water aquifer

system. Two types of tillage practices commonly used in the production of field crops are conventional and conservation tillage. Conventional tillage utilizes the maximum amount of soil tilth with the majority of the crop residue being incorporated deeply into the soil. Water run off is the greatest for this type of tillage system. Leaching of the nitrates is believed to be less from conventional tillage practices while nitrate runoff is expected to be greater. Conservation tillage is a soil tilth practice designed to control soil erosion or surface water runoff. Crop residue is left on the soil surface and a minimum amount of deep tillage incorporation is applied to the soil. Since more of the crop residue is left near the soil surface, there is less runoff and more concern that the chemical leaching potential may increase (Crowder and Young, 1988; United States Environmental Protection Agency, 1979; and Hallberg, 1986d citing Baker, 1985; Baker and Laflen 1983; and Hinkle, 1983).

There has been some discussion in the literature that for ammonium nitrate, conservation tillage may actually tie up the soluble nitrogen in the residue and act as a controlled release source. Nitrates, as a result, do not leach out of the root zone as rapidly, allowing for more effective use of the fertilizer and less contamination potential for the ground water (Swoboda, 1977).

Once the chemical has reached the aquifer, the movement is affected by various factors including hydrostatic pressure,

recharge and discharge rates, sorption retardation, dispersion, non-uniform flow conductivity and storativity characteristics (Canter, Knox and Fairchild, 1987; Sharefkin, Schechter and Kneese, 1984; Pye, Patrick and Quarles, 1983; Novotny and Chester, 1981; and Spence and Starrett, 1975). Modeling the movement of water in an aquifer is area specific and depends on the subsurface structure, amount and formation of rock, sand, porosity, and fissures among other physical characteristics. Various research and modeling attempts to model ground water movement in detail have been conducted for specific areas (Gorelick, 1983; Gorelick and Remson, 1982; Wilson and Miller, 1978; Bredehoeft and Pinder, 1973). The information required to utilize detailed hydrology models is difficult and expensive to obtain, especially if examining a regional ground water system from which there are many different aquifers and soil structures.

A debate has existed among the physical scientists as to whether field applied nitrogen fertilizers actually were the source of the increase in nitrate concentrations in ground water. Research, however, has begun to establish some relationships between nitrogen fertilizer application and nitrate contamination of ground water. Several research projects have determined that nitrate loss below the crop root zone and nitrate leaching to shallow ground water aquifers are directly related to fertilization rates and fertilization history (Hallberg, 1986d citing; Hallberg, 1986a; Hallberg,

1986b; Hallberg, 1986c; Keeney, 1986a; Keeney, 1986b; Adelman, Schroeder and Wallin, 1985; Baker, 1985; Hallberg, 1985; Olson, 1985; Hallberg, Libra and Hoyer, 1985; Hallberg, Libra, Bettis III and Hoyer, 1984; Baker and Johnson, 1983; Hill, 1982; Olson, Frank, Grabouski, and Rehm, 1982; Baker and Johnson, 1981; Singh and Sekhon, 1978/79; Chichester, 1977; and Olsen, Hensler, Attoe, Witzel and Peterson, 1970).

A study conducted in the Big Springs basin of Iowa was one of the more extensive and complete research projects which analyzed chemical nitrogen fertilizer application and nitrate contamination of ground water (Hallberg, 1986 citing Blodgett and Clarke, 1986; Clark and Richardson, 1986; Devault, 1986; Elfving, 1986; Hallberg, 1986c; Hallberg, 1986a; Hallberg, Libra and Hoyer, 1985; and Hallberg, Libra, Bettis and Hoyer, 1984). The Iowa study area was 103 square miles with agriculture as the only industry. Annual statistics were collected on land treatment, farming practices, and agricultural chemical use. Nitrogen fertilizer application and increases in ground water nitrate levels had a near linear relationship. The data further indicated that 50 to 60 percent of the field applied nitrogen fertilizer was lost through processes other than removal from grain production.

The Big Spring Basin study was site specific and the nitrate leaching potential may differ across the United States for different soil characteristics and cropping practices. However, the research results did provide numerical

documentation of the ground water contamination potential from nitrogen fertilizers.

CHAPTER III

METHODOLOGY AND SCOPE

Study Area

Isolating a regional area vulnerable to ground water contamination was difficult due to the absence of an accurate nationwide data base. Few studies to date have been conducted which attempt to isolate vulnerable contamination areas throughout the United States (Crutchfield, 1989; and Nielson and Lee, 1987).

Crutchfield (1989) characterized the ground water pollution problem by combining information on ground water vulnerability with data on agricultural chemical use. Regional contamination information was obtained from the study. The Appalachian region was identified as having the potential for nitrate contamination of ground water.

Nielson and Lee (1987) attempted to identify the national magnitude of ground water contamination from nonpoint agricultural sources. Information required for the study included land use, agricultural practices, climate, hydrology, soil characteristics, net aquifer recharge rate, depth to the water table, and characteristics of the aquifer. The Depth to Water, Recharge (net), Aquifer Media, Soil Media, Topography (slope), Impact of the Vados Zone, and Conductivity

(hydraulics of the aquifer) model (DRASTIC) was used to isolate vulnerable agricultural nonpoint chemical contamination areas (Kerr, 1985). Results from the study indicated that Tennessee was not excluded from vulnerability to nonpoint agricultural chemical contamination. Harding and Decatur counties were identified in South Central Tennessee as being vulnerable to nitrogen nitrate contamination (Figure 3). Although identified by DRASTIC as vulnerable to nonpoint agricultural contamination, Harding and Decatur counties were not selected as the study area. Dr. Paul Denton³, based on collected data and his knowledge of soils, cropping practices, chemical application, and characteristics of ground water in Tennessee, suggested the area identified by DRASTIC may not be the most conducive for developing a methodology for examining ground water contamination from field applied nitrogen fertilizers. Field crops which require chemical nitrogen fertilizer, such as corn, were not extensively grown in Harding and Decatur counties and thus contamination from nitrogen fertilizer was not expected.

Dr. Paul Denton recommended three counties in the Northwest part of the state as areas vulnerable to contamination from nonpoint agricultural chemicals. Obion, Weakley, and Gibson counties were selected as the study area (Figure 3).

³ Personal communication with Dr. Paul Denton, Department of Soil Science, University of Tennessee.

TENNESSEE

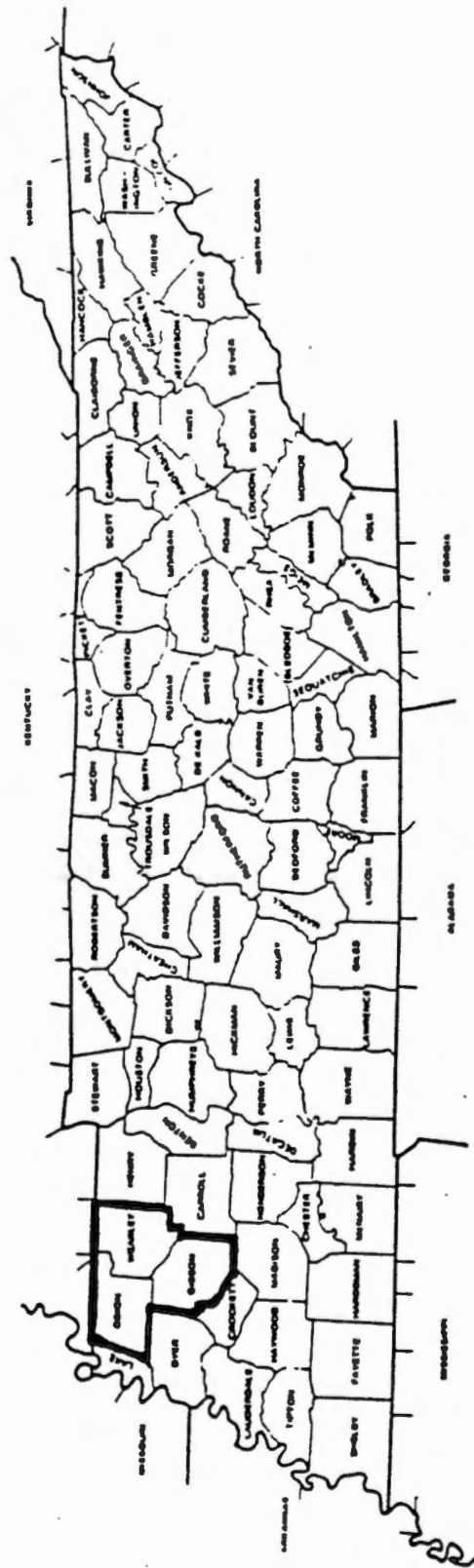


Figure 3. Study Area.

Source: Census of Agriculture, 1987.

The three counties selected were located in the same crop and livestock production area, indicating similar agricultural practices and types of farming enterprises (Mundy and Gray, 1986). The region was categorized as Major Land Resource Area (MLRA) 134 by the Soil Conservation Service. MLRA 134 was classified as the Southern Mississippi Valley Silty Uplands. The majority of land acreage was utilized for farms, with cash crops being the main income enterprise. Corn, soybeans and wheat were the primary cash crops in the northern part of MLRA 134. Precipitation and groundwater were abundant with most of the precipitation occurring during the winter and spring season. Elevation ranged from 25 to 100 meters (USDA, 1981).

Demographic statistical characteristics related to the three county region are presented in Figure 4. The three county area was largely rural with only 42 percent of the population classified as urban. Incorporated cities which exist in the selected region had populations which were less than 11,000.

OBION COUNTY:

AREA SQUARE MILES:	550	
POPULATION PER SQUARE MILE:	59.6	
POPULATION:		
URBAN:	13,171	(40.2%)
RURAL:	19,610	(59.8%)
INCORPORATED CITIES:		
SOUTH FULTON:	POPULATION:	2,375
UNION CITY:	POPULATION:	10,436

WEAKLEY COUNTY:

AREA:	SQUARE MILES:	581	
POPULATION PER SQUARE MILE:		56.6	
POPULATION:			
URBAN:		14,394	(39.5)
RURAL:		23,766	(60.5)
INCORPORATED CITIES:			
MCKENZIE	POPULATION	5,405	
MARTIN	POPULATION	8,989	

GIBSON COUNTY:

AREA SQUARE MILES:	602	
POPULATION PER SQUARE MILE:	82.2	
POPULATION:		
URBAN:	22,893	(46.3%)
RURAL:	26,574	(53.7%)
INCORPORATED CITIES:		
HUMBOLDT:	POPULATION:	10,290
MILAN:	POPULATION:	8,083
TRENTON:	POPULATION:	4,601

Figure 4. Demographics of Study Area, 1980 Data.

Source: Center for Business and Economic Research, 1989

Methodology

Economic analysis related to attaining quality point of use ground water, which has been contaminated by agricultural chemicals, was complex and required economic, biological, agronomic and hydrologic information. Previous economic research has focused on the benefits or costs of contamination prevention strategies, has been directed toward point source pollution, has examined nitrogen contamination resulting from irrigation return flows and has been a static economic analysis (Klinko and Abdalla, 1989; Anderson, Opaluch and Sullivan, 1985; Schechter, 1985; Sharefkin, Mordechai and Kneese, 1984; Raucher, 1983; Heady and Vocke, 1979; Horner, 1975).

Use of nitrogen fertilizer as a factor input by the agricultural crop production sector imposes a potential externality on the consumers of nitrate contaminated ground water. Estimating the cost for achieving nitrate contamination standards, for point of use ground water, required both the cost impacts incurred by producers and the cost of nitrate removal borne by the consumer. The natural removal of nitrates from ground water needs to include hydrologic aspects, which require the time variable to be implicit in the overall economic analysis.

Various modeling and estimation techniques were used in the analysis. The different modeling techniques were

categorized as dynamic optimal control, prevention, and point of use nitrate removal. A schematic diagram of the modeling components, interrelationships, inputs required, and output generated are presented in Figure 5. The minimum cost to a region of obtaining water quality (prevention or point of use contaminant removal) over time was identified in the dynamic optimal control section. Optimal control modeling techniques were used for the dynamic analysis (Figure 5, Box 1). Information required by the dynamic optimal control modeling component included impacts to agriculture (prevention policy option section) and removal of nitrates from water (nitrate removal option) (Figure 5). Statistical estimation techniques were used to transform the data obtained from the prevention policy and nitrate removal sections for use as parameters in the dynamic optimal control model (Figure 5, Box 2).

The prevention policy option focused on agricultural production, and required the producer to discontinue use of the chemical or adjust production practice methods to reduce the contamination of ground water. Data output from the preventive strategy analysis included an estimate of regional agricultural costs resulting from implementing a reduced nitrate contamination ground water policy. Restrictive fertilizer use and various types of production practices and crop rotations to reduce contamination of ground water were included as available production strategies. Economic costs associated with the preventive strategy were reflected through

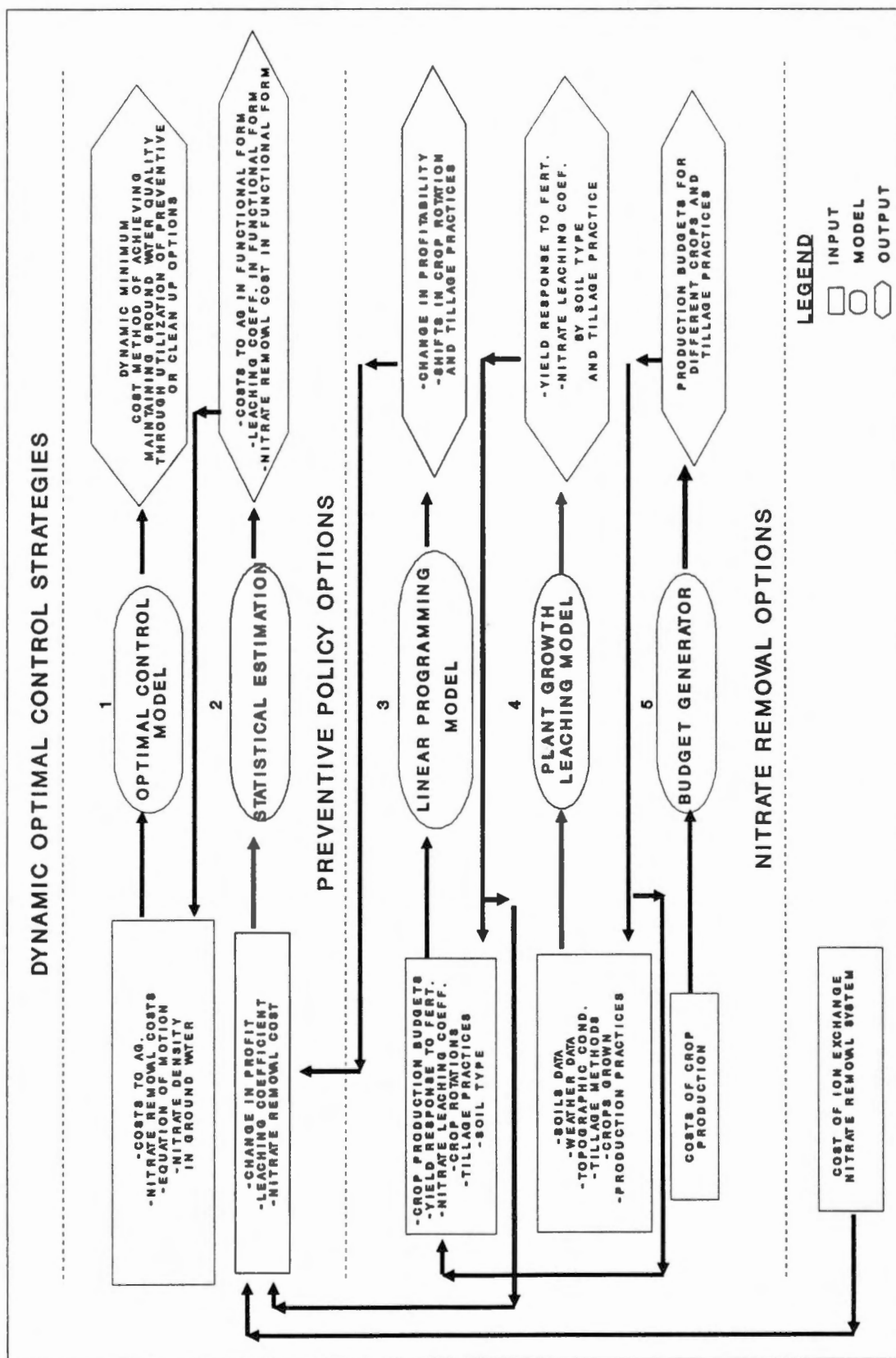


Figure 5. Modeling Strategy and Interaction.

changing net revenues in the agricultural sector as fertilizer use was restricted and crop rotations and tillage practices were adjusted. Linear programming was used to obtain agricultural cost information for the optimal control model and was the main economic modeling tool used to determine the minimum cost of obtaining nitrate standard water quality (Figure 5, Box 3). The linear programming model also provided information regarding changes in cropping patterns and tillage practices. A chemical leaching and plant growth simulator was used to determine yield, tillage practice, fertilizer and nitrate leaching relationships (Figure 5, Box 4). Output generated was used in both the linear programming and optimal control models. A budget generator and farm financial simulator, provided crop and tillage practice budget information and was used mainly for support of the linear programming model (Figure 5, Box 5).

Dynamic Optimal Control Abatement Strategies

Classical economic theory employs a static framework as the analytical setting. Economic analysis of achieving/maintaining ground water quality contaminated by agricultural chemicals involves time. The contamination process and preventive measures are both associated with time.

A methodology used to analyze economic problems which involves time as an explicit variable were identified in the literature as optimal control theory or dynamic optimization.

Optimal control theory methodology is a mathematical method used to analyze intertemporal economic problems (Clark, 1976; and Dorfman, 1969). Various issues related to agricultural economic problems have been addressed by use of optimal control methods. Selected research which has applied optimal control theory techniques to agricultural economic problems include: determination of optimum public rangeland grazing fees (Huffaker, Wilen and Gardner, 1989), public policy addressing ground water mining and determining switching points from local ground water to imported surface water (Kim and Moore, 1988), selecting a pesticide application strategy in relation to increasing pest resistance to the pesticide (Plant, Mangel, and Flynn 1985; and Hueth and Regev, 1974), determining a solute transport equation in ground water flow (Hwang, Cho and Yeh, 1984), and developing an economic and hydrologic model to determine the optimal interseasonal allocation of water for irrigation (Worthington, Burt and Brustkern, 1985). Optimal control theory methodology, however, has not been applied to the problem of nonpoint agricultural chemical contamination of ground water and associated abatement strategies such as changing production and rotation practices, restricting agricultural input use, and point of use clean up of ground water.

Optimal control theory allows incorporation of modeling techniques which determine the optimal time path for economic variables specified by the researcher. Intrilligator (1971)

discussed the optimal control theory setting and defined the dynamic economizing problem as "that of allocating scarce resources among competing ends over an interval of time from initial time to terminal time." Terminology used in optimal control theory include: state variables, control variables, equation of motion, and objective functional. The state variable refers to the state of the system at any time t , and describes the decision makers environment. Control variables represent the decisions or available choices that can be made at any time t , and are subject to value constraints. The equation of motion as quoted from Intrilligator (1971 p. 292) "is a set of n differential equations given the time rate of change of each state variable as a function of the state variable, the control variable, and time." The objective functional "is a mapping from control trajectories to points on the real line" (Intrilligator, 1971, p. 292). The objective functional is not called a objective function because the algorithm is solving for a function and not a specific point. Optimal control theory techniques were used in this study to analyze the dynamic economic aspects of achieving maintaining ground water quality.

Several dynamic variables enter into the process of determining a minimum cost strategy for achieving ground water quality. A policy of restricting present fertilizer use allows water quality to be obtained in a future time period with less water filtration required. No restrictions on

fertilizer application would result in continued contamination of the aquifer and increased nitrate removal costs. The minimum regional cost of obtaining clean point of use ground water, which has been contaminated from agricultural chemicals, was estimated dynamically with a optimal control model.

Preventive Policy Options

Preventive options and associated agricultural industry costs were estimated by examining changes in net revenue (obtained from the linear programming model to be discussed in a later section). Based on production theory concepts, the profit maximizing point for the region occurs where marginal revenue equates marginal cost. The linear programming model selects the profit maximizing nitrogen level based on marginal economics. Once the optimal nitrogen level has been identified changes in net revenue, associated with the maximum profit, may be determined. Mapping the changes in net revenue from the optimum allowed development of a loss function, which represented the cost to agriculture of restricting nitrogen fertilizer. Statistical estimation techniques were utilized to estimate the parameter values of the function.

The nitrate removal cost was a function of the density of nitrate in the ground water at point of use. Nitrate concentration in ground water were reflected in the equation of motion. Statistical regression analysis was used to

project the different clean up costs associated with various levels of nitrate density in point of use ground water.

Estimating the economic impacts (changes in net revenue) from restricting agricultural nitrogen fertilizers to achieve ground water quality required the use of several modeling tools. Included were a linear programming model, a budget generator and farm financial simulator, and a chemical leaching and plant growth simulator.

Production of field crops requires the use of nitrogen fertilizer as a plant nutrient to achieve yield goals. Restricting the use of nitrogen fertilizer would, at the very least, reduce per acre crop yields and a farm operator would ultimately adjust his/her production practices to maximize profit⁴.

Imposing restrictive management practices on the production of field crops, which reduce nitrate leaching, was another alternative available for achieving improved ground water quality. Potential production adjustments included in the analysis were changing crop enterprise rotation strategies and altering cultivation practices (conventional tillage versus conservation tillage). Conservation tillage restricts the surface flow of water runoff (United States Environmental

⁴ Utilizing slow release fertilizers or the application timing of nitrogen are other management strategies which have been researched for reducing nitrate loss (Kerr, 1977, and Nielson and Lee, 1987). Nitrogen application timing strategies or use of slow release fertilizers will not be included in the analysis, but warrant further investigation.

Protection Agency, 1979; and Soil Conservation Society of America, 1979). The restricted surface flow has the potential to increase the percolation of water and nitrate to the subsurface. Switching from conservation tillage systems to a conventional tillage system may be an economically viable option to meet ground water standards⁵.

Linear programming model. The economics of agricultural production required the efficient allocation of limited resource inputs among competing production enterprise alternatives. A mathematical means was required to examine the economic impacts imposed on the agricultural sector resulting from a policy of restricting an input. Reducing the nitrate concentration of ground water by restricting the use of nitrogen fertilizer in the production of field crops results in a resource allocation problem. Linear programming methodology provides the mathematical means to analyze such an allocation problem. Linear programming has been a common mathematical tool used to study the problem of efficiently allocating limited resources among competing agricultural production enterprises (Hillier and Lieberman, 1986).

A profit maximizing linear programming model was used as the main economic model to evaluate the costs associated with

⁵ A policy conflict may develop, however, between conservation tillage for the prevention of soil erosion and conventional tillage for improved ground water quality. The controversy surrounding tillage practices to achieve different environmental goals was beyond the scope of this study.

the preventive approach to controlling ground water contamination. Selected crops were incorporated as various crop rotation alternatives. Conventional and conservation tillage were the crop production management alternatives associated with each crop rotation.

The potential for agricultural chemical leaching is related to soil characteristics. Some soils provide a better medium for the leaching of agricultural chemicals while others act as a prohibitor. Included in the linear programming analysis were 19 different soil classifications. The soil classifications were identified and selected from a soil map for the study area and from discussions with Dr. Paul Denton⁶. Crop yield and leaching coefficients associated with different soil classifications, fertilizer applications, crop rotations, and tillage practices were incorporated into the linear programming model. The yield and nitrate leaching response coefficients were obtained from the chemical leaching and plant growth simulator.

Chemical leaching and plant growth simulator. Estimation of the nitrate leaching process involved the modeling of various hydrologic as well as soil characteristics. A plant growth and leaching model was utilized to determine leaching coefficients and crop yield responses to fertilizer

⁶ Personal communication with Dr. Paul Denton, Department of Soil Science, University of Tennessee, Knoxville, 1990.

restrictions, tillage practices and crop rotation scenarios. Several plant growth or soil leaching models were available and described in the literature including: DRASTIC (Kerr, 1985), Cerres-Maize (Jones and Kiniry, 1986), SOYGROW (Soybean Crop Growth and Yield Model) (Wilkerson, Jones, Boote and Mishoe, 1985), and the Erosion Productivity and Impact Calculatory (EPIC) (Putman and Dyke, 1987). However, isolating a model which included plant growth, yields, fertilizers, and weather relationships for multiple crops and, in addition, included a chemical leaching component was more difficult.

EPIC includes model simulation techniques which capture the effects of multiple plant growth, different soils, tillage practices, yields, and chemical leaching. The chemical leaching and plant growth simulator chosen was EPIC.

EPIC simulates plant growth on daily step intervals, is initiated by simulating a weather day and traces impacts through each of the submodels, including submodel interactions. Output from the model is calculated daily, and includes such items as chemical leaching, plant growth and yield, and erosion. EPIC also computes daily balances as inputs to the succeeding day for such variables as soil moisture, nutrient levels, biomass, and residue. A stochastic series of daily weather events drives the EPIC model and initiates day to day changes in values of the various physical and chemical processes. The EPIC model is static with respect

to management and technology and thus once specified it cannot be altered during simulation (Putman and Dyke, 1987).

The EPIC model is composed of several submodels which physically simulate weather, hydrology, sheet, rill, and wind erosion, plant nutrients, plant growth, soil tillage and management, and plant environmental control (Figure 6).

Precipitation, air temperature, solar radiation, and wind are required weather parameters for operating EPIC. The Universal soil loss equation and the Onstad-Foster equation are utilized for the soil erosion submodel. A special equation is developed for wind erosion.

Volume and peak discharge rates of surface run off are calculated in the hydrology submodel. Infiltration, percolation, lateral subsurface flow, drainage, evapotranspiration, irrigation, and snowmelt are also estimated and used primarily to compute and revise soil moisture levels to begin the next daily cycle. The plant nutrient submodel provides information for three plant nutrients: nitrogen, phosphorous, and lime. Nitrogen fertilization, nitrogen fixation, rainfall nitrogen, mineralization, denitrification, immobilization, leaching of nitrates, upward nitrate movement by soil water evaporation, crop uptake, organic N transported by sediment, and nitrate concentrates in runoff are estimated. Mineralization, fertilization, sorption-desorption, immobilization, crop uptake, runoff of soluble P, and sediment transport of mineral

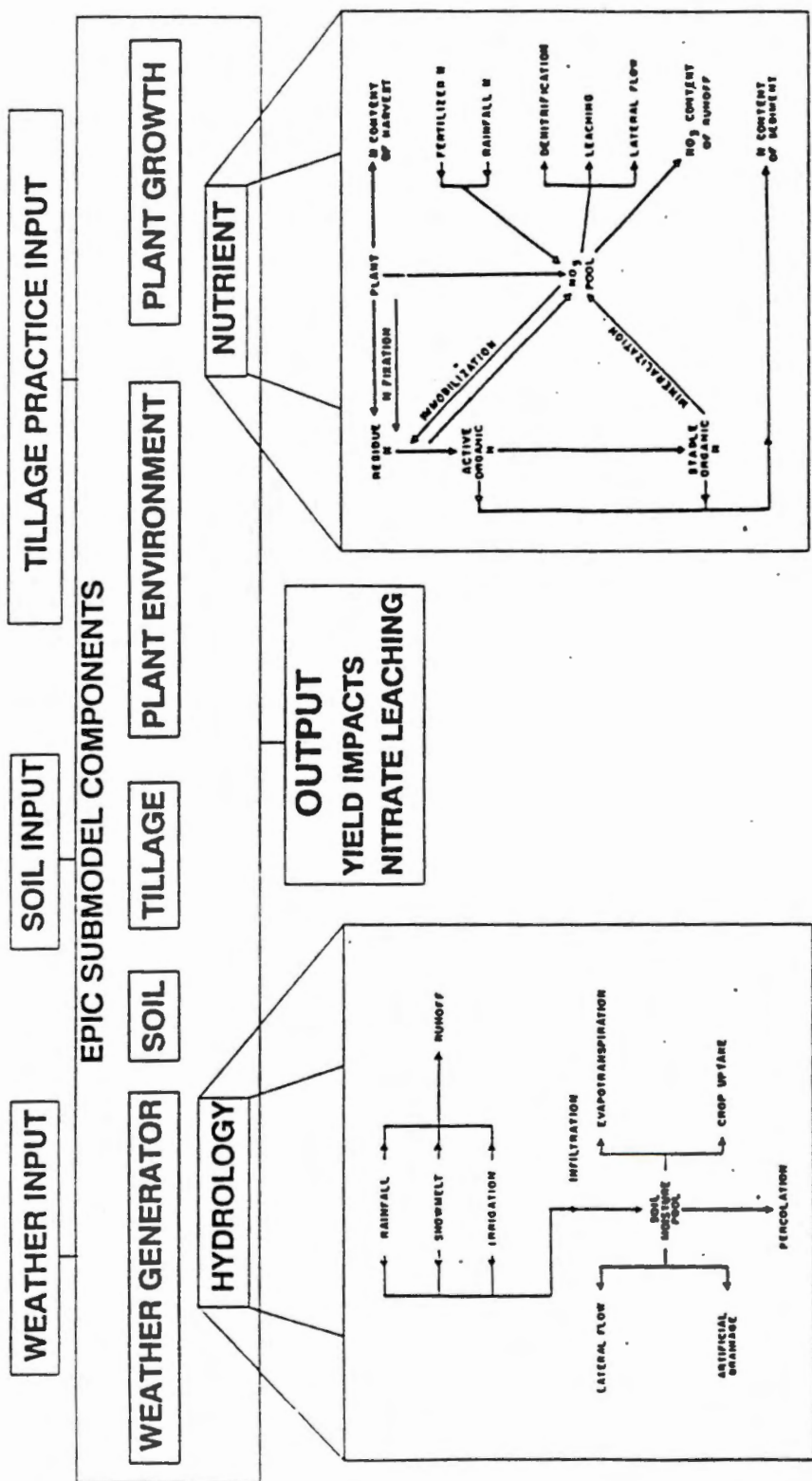


Figure 6. EPIC Input, output and Submodel Components.

and organic phosphorus are also estimated. The lime nutrient is simulated to neutralize toxic levels of aluminum in highly weathered soils and in moderately weathered soils to maintain soil Ph.

The plant growth submodel may be used with corn, wheat, grain sorghum, soybeans, cotton, peanuts, alfalfa, grasses, oats, and barley. Above ground biomass, root, grain and fiber production, moisture and nutrient uptake, energy interception, and energy conversion to the roots are estimated in the submodel. The constraining factors to plant growth are water, nutrients, and temperature.

The soil submodel allows for 10 layers of soil to be used in the simulation. Thickness of soil layers, bulk density, water holding capacity, minimum field capacity, wilting point, organic nitrogen, nitrate, labile P, crop residue, sum of bases, organic C, CaCO_3 , coefficient of linear extensibility, percentages of sand, silt, clay and fragment inclusion are included in the soil submodel. Changes in soil properties are also identified.

The plant and environmental control submodel includes irrigation, fertilization, lime, and pesticide functions.

Crop rotations and crop budgets are integral components of the tillage and management submodel. The submodel will accept a maximum of 6 crop rotations including 6 individual crops.

The submodel maintains a daily account of standing and flat residue and the gradual change between the two. Soil settling and smoothing is computed after each rainfall event. After a tillage operation, the percentage of crop residue incorporation, nutrient mixing, and change in bulk density are computed for the depth of soil penetration, and surface ridging, height interval, and roughness are adjusted (Putman and Dyke, 1987, p. 13).

EPIC provided information on crop yield and nitrogen leaching from various tillage practices, soil classifications, weather variables and nitrogen fertilizer application rates. Information from EPIC was included in the linear programming model to identify optimal cropping practices, management strategies, and associated yield and leaching potentials. EPIC was also used to provide nitrogen leaching information to the optimal control model.

Budget generator and farm level simulator. A budget generator and farm level simulator provided budgetary information for the linear programming model. The budget generator and farm level simulator provided information on the ownership and operating costs of crop production for different tillage practices and crop enterprises.

Several budget generators have been developed and were available for use. Budget generators considered for use in this study included: a Texas A&M farm budget generator (McGrann, Olson, Powell, et. al, 1986), a North Carolina farm budget planner (Hoag, 1987), a University of Tennessee crop enterprise budget generator (Johnson, L. A., 1987), and the

Firm Enterprise Data System (FEDS) crop and livestock budget generator (Kletke, 1979).

The North Carolina budget planner has been identified as a very useful and practical model for obtaining costs of production for crops and different tillage practices (Cole and English, 1990). The North Carolina budget planner was selected for use in this study.

The most recent work in farm level modeling involved the development of FLIPSIM V (Richardson and Nixon, 1986) which was identified as the most complete farm level simulator (Cole and English, 1990). FLIPSIM V was selected as the farm level simulation model for use in this study. Combining information from the North Carolina Budget Generator and FLIPSIM V, crop production budgets were developed for use in the linear programming model.

The primary role of the farm level simulation model was to aggregate costs from the budget generator and incorporate realistic fixed costs, such as debt on assets. Utilizing the farm level simulator allowed more flexibility in establishing desired debt and loan payment characteristics, not available in the North Carolina Budget Generator. FLIPSIM V allowed partial debt analysis on assets, contrary to the North Carolina Budget Generator where debt was either included as a total asset value or not estimated.

Nitrate Removal Strategy

Current water treatment for households and public utilities include settling, coagulation, filtration, carbon absorption, chlorination, and ozonation; none which were capable of removing nitrates from water. The nitrate chemical requires specific treatment methods for removal from water supplies. Six treatment methods have been used or are being studied: ion exchange, reverse osmosis, electrodialysis, biological denitrification, chemical reduction, and distillation. However, only two of the processes have potential for full scale application, with the others only partially removing nitrates. The two most feasible alternatives were reverse osmosis and ion exchange.

Reverse osmosis removes only a portion of the nitrate from water (60 to 70 percent). Water is forced across a semipermeable membrane to remove nitrates (Nielsen and Lee, 1987; United States Environmental Protection Agency, 1983; Clifford and Weber, 1978; and Pojasek, 1977).

The advanced treatment process most economical and practical was ion exchange. The ion exchange procedure involves the process of trading ions (electrically charged particles). The appropriate ion exchange method for nitrate is anion exchange. Removal of nitrate ions occurs as the water is passed through a bed of ion exchange resins. The ion exchange process of removing nitrate from water does not break down or convert the chemical to another form, thus disposal of

contaminated resins is required. The ion exchange process is more suitable as a nitrate removal system than reverse osmosis. Ion exchange requires lower initial and annual operating costs, requires no additional well site storage, has higher water recovery, produces a more concentrated water brine, requires fewer automatic and electrical controls, has greater reliability, uses less energy, and can be operated on demand. The on-off operation of the ion exchange system is a significant advantage over reverse osmosis which requires processed water storage facilities and repressurization each time the system is turned on. Difficulties associated with ion exchange include selecting a resin of high selectivity for nitrate over other ions, and the disposal of resin regenerant (Guter, 1982). The ion exchange system can be used in household (system is about the size of a water softener), or on a larger scale. Estimated costs associated with the ion exchange process for a household, without including maintenance costs, range from 500-800 dollars (Nielson and Lee, 1987).

CHAPTER IV

RESTRICTING NITROGEN FERTILIZER

Development of the Linear Programming Model

The purpose of this chapter was to provide a discussion of the economic impacts imposed on agriculture as a result of achieving ground water quality through preventive nitrogen fertilizer use policies. Economic modeling components which were introduced in Chapter III were further developed, including the linear programming model, farm budgets, and the chemical leaching and plant growth simulator. Information obtained from the economic analysis were used as input data in the dynamic optimization segment of the study.

Cash grain and nondairy livestock farms were identified as the most predominant farming enterprises for the study area. Soil and crop production characteristics of the cash grain farms in the study area were utilized to develop farm budgets, the chemical leaching and plant growth simulator, and the linear programming model. Soybeans, corn, and wheat were the three most important crops produced in the region, with the majority of cropland being used for soybean production (Mundy and Gray, 1986). Corn-soybean-wheat/soybean double crop, corn-soybean, and continuous corn were common rotation practices used in the study area.

Several tillage methods were used in the study area. Conventional tillage⁷ practices accounted for approximately 80 percent of the corn, soybean and sorghum acreage (Tennessee Department of Agriculture, 1989). Approximately 12 percent of the corn, soybean and sorghum acreage were tilled using a no till⁸ system. Other conservation⁹ tillage practices were used on 8 percent of the acreages.

The input data used for the three preventive modeling components were based on economic conditions, topographic properties and soil profile characteristics which represented the study area. The majority of soils were classified as Udalfs. Soils selected for the analysis included the most prevalent for the three county study area:¹⁰ Adler, Birds, Calloway, Collins, Convent, Falaya, Grenada, Loring,

⁷ Conventional tillage is a "system where 100 percent of the surface layer is mixed or inverted by plowing, power tilling, or multiple disking" (Tennessee Department of Agriculture, pp. 122, 1989).

⁸ No till is "a procedure whereby a crop is planted directly into a seed bed not tilled since harvest of a previous crop or the planting of a crop into sod, previous crop stuble or a cover where only the intermediate seed zone is disturbed" (Tennessee Department of Agriculture, pg. 122, 1989).

⁹ Other tillage is defined as "tillage practices prior to planting which result in a minimum of 30 percent ground cover or residue being retained on the surface following planting. Grass and weed control is accomplished primarily with herbicides. Includes ridge-till, strip-till, and mulch till" (Tennessee Department of Agriculture, pg. 122, 1989).

¹⁰ Personal communication with Dr. Paul Denton, Department of Soil Science, University of Tennessee; and USDA, 1973; USDA, 1973b: USDA, 1973c.

Lexington, Memphis, Providence, and Waverly. The selected soils were further categorized by field slope since topographic conditions, in addition to soil profile characteristics, impact yield potential (Buntley and Bell, 1976).

Acreage distributions for each of the soil types (soil types were those soils categorized by soil characteristics and field slope) were derived using the National Resource Inventory (NRI) (USDA, 1982) and Tennessee Agriculture (Tennessee Department of Agriculture, 1989) statistics. The NRI provided acreage distribution by crop, soil, and slope for the three county study area. Percentage distributions for the selected soils, as defined by the NRI, were used in combination with the total acreage data from Tennessee Agriculture to determine the acreage distribution for the study area. The percentages were multiplied by total acreages representing the 1985-1989 as reported in Tennessee Agriculture for the three counties. The acreage distribution and associated percentages for each soil type are presented in Table 1.

Conventional and conservation tillage practices were the two land management strategies used for the analysis. Conventional tillage was defined as practices including annual chisel plowing, spring disking and row cultivating for weed control during the growing season. Conservation tillage was defined to include chisel plowing every third year as the only

Table 1. Acreage Distribution by Soil Type.

Soil Type	Slope	Acreage	Percent
	percent		
Falaya	2	78,991	16.9
Collins	2	59,360	12.7
Loring	3	58,892	12.6
Grenada	3	45,805	9.8
Waverly	2	36,457	7.8
Loring	6	28,511	6.1
Grenada	7	27,577	5.9
Calloway	4	27,577	5.9
Loring	10	21,500	4.6
Providence	6	18,229	3.9
Memphis	3	13,555	2.9
Memphis	6	12,152	2.6
Calloway	1	10,750	2.3
Adler	2	8,881	1.9
Birds	1	5,609	1.2
Lexington	5	4,207	0.9
Convent	2	3,739	0.8
Lexington	12	2,804	0.6
Memphis	12	2,804	0.6
Total		467,400	100.0

implemented tillage practice, with chemicals being used for weed control during the growing season instead of row cultivation. Continuous corn, corn-soybean-wheat/soybean double crop, continuous soybeans, continuous wheat and continuous hay production were included as crop rotations. Continuous soybean, wheat and hay crop rotations were included in the linear programming model as possible substitutes for the more nitrogen demanding rotations (continuous corn). Alternative crop rotations which require less nitrogen fertilizer were hypothesized to be a feasible production alternative when nitrogen fertilizer restrictions were imposed.

Crop yields, net revenue, and nitrate leaching representing each rotation, tillage system, fertilizer level and soil type were included in the linear programming model. Field applied nitrogen fertilizer levels associated with each rotation and soil type were restricted from base levels in 20 percent reduction intervals.

The linear programming model was a net revenue maximization model. The objective function and constraints for the model were specified as:

$$\text{Maximize: } obj = \sum_s \sum_r \sum_p \sum_f R_{srpf} Y_{srpf} - \sum_c P_c X_c$$

subject to the following constraints

$$\sum_r \sum_p \sum_f A_{srpf} Y_{srpf} \leq AC_s \quad s=1 \dots 19$$

$$\sum_s \sum_r \sum_p \sum_f Y_{srpf} CP_c + PP_c X_c \geq DD_c \quad c=1 \dots 3$$

$$\sum_s \sum_r \sum_p \sum_f Y_{srpf} FU_{srpf} = TN$$

$$\sum_s \sum_r \sum_p \sum_f Y_{srpf} L_{srpf} = TL$$

Where:

obj is the objective function value;

s is the soil type 1...19;

r is the crop rotation 1...5;

p is the tillage practice 1,2;

f is the field applied nitrogen fertilizer requirement;

c is the individual crop 1...4;

R is the net revenue for an activity;

Y is the level of activity related to crop production;

P is the cost of purchasing grain;

X is the level of crop buying activity;

AC is the acreage constraint;

TN is the total nitrogen fertilizer available for the region;

A is the acreage use coefficient;

CP is the crop production;

FU is the fertilizer use coefficient;

L is the nitrate leaching activity;

TL is the total nitrate leaching for the study area;

PP is the level of crop purchase; and
DD is the regional crop demand 1...4.

A base solution was established by maximizing net revenue with unconstrained fertilizer availability and nitrate leaching. Total fertilizer availability for the region, as determined from the unconstrained base solution, was restricted by 10 percent intervals, obtaining 10 different scenarios. Grain buying activities allowed commodity demand to always be satisfied for the region. Prices for purchasing grain were established in accordance with the future market price: \$2.89 for corn, \$6.21 for soybeans and \$3.35 for wheat (Wall Street Journal, June, 1990).

Data Input for the Linear Programming Model

The linear programming model utilized several types of input data. Crop production budget data related to producing different crop rotations and tillage practices were developed. Activities which represented reductions in field applied nitrogen fertilizer for each crop rotation and tillage practice were incorporated into the linear programming model. Net revenue, yields, and leaching were adjusted to reflect various levels of field applied nitrogen fertilizers.

Budget information¹¹. Crop production costs were based on a 360 acre farm for the study area of which 350 was tillable, 230 was owned and 130 was leased. The budgets, including variable and fixed costs for each rotation and tillage practice, are presented in Appendix A. Production costs were adjusted to reflect the reduction in total cost as a result of using less nitrogen fertilizer. Field applied nitrogen fertilizer was reduced in 20 percent increments. The price used for field applied nitrogen fertilizer was \$.22/lb. (Johnson, 1989). A summary of the production costs used to develop net revenue by rotation, tillage practice and field applied nitrogen fertilizer are presented in Table 2.

Nitrate leaching and yield response. The EPIC model provided information on yield and nitrate leaching response to various application levels of nitrogen fertilizer for each crop rotation, soil type and tillage practice. Variations in yield, as a result of different nitrogen fertilizer application rates, were used to identify associated net revenues. Nitrate leaching response was used in the optimal control model to establish a relationship between the amount of nitrate leaching to ground water and various nitrogen fertilizer application rates.

Data input requirements for the EPIC model were

¹¹ For a more detailed description of the costs incorporated in the farm budgets including machinery cost, etc., see Coady, Cole and English, 1990.

Table 2. Production Costs by Rotation, Tillage Practice,
and Fertilizer Use Level.

Nitrogen Fert. Use Level	Conventional Tillage Costs	Conservation Tillage costs
percent		
.....Corn-Soybean-Wheat/Soybean Rotation.....		
	\$/3 acres	\$/3 acres
100	488	502
80	480	494
60	472	486
40	464	478
20	456	471
0	448	463
.....Corn-Soybean Rotation.....		
	\$/2 acre	\$/2 acre
100	293	325
80	285	317
60	277	309
40	269	301
20	261	293
0	253	285
.....Continuous Corn.....		
	\$/acre	\$/acre
100	181	188
80	176	183
60	171	177
40	165	172
20	160	167
0	155	162
.....Continuous Wheat.....		
	\$/acre	\$/acre
100	119	132
80	120	129
60	114	126
40	111	124
20	108	121
0	106	118

Table 2. Continued

Nitrogen Fert. Use Level	Conventional Tillage Costs	Conservation Tillage costs
percent		
.....Continuous Soybeans.....		
	\$/acre	\$/acre
0	125	136
.....Hay.....		
	\$/acre	
100	158	-
80	155	-
60	153	-
40	150	-
20	147	-
0	145	-

substantial. Although various plant growth and tillage data in the model were provided by the authors of EPIC, soil characteristics, topography, and weather pattern input required adjustment to more accurately reflect conditions of the study area.

Soil characteristics and profile input data sheets for EPIC were constructed using soil survey information for each county¹² in the study area (United States Soil Conservation Service, 1979. 1967a, 1967b, and 1966). Soil input characteristics used in the EPIC model are presented in Appendix B.

Daily weather data was obtained from published information provided by the Milan Experiment Station¹³. The time period of the weather data information included the years 1950-1989. Precipitation, temperature, along with related statistical information which was used in the EPIC model for the study area is presented in Appendix C.

Additional information which was specific to soil tillage, crop rotation and to the study area included the channel roughness factor, manning's surface roughness factor, and the runoff curve number. The channel roughness factor was

¹² Consultation with Dr. Paul Denton, soil science department, provided a substantial amount of information regarding the assimilation of soil and topographic information.

¹³ Dr. Joanne Logan, Department of soil science, assisted in assimilating the data provided by the Milan experiment station.

established at .035 for conventional tillage. The surface roughness factor was established at .15 for conservation tillage and .30 for conservation tillage. Additional information which was specific to soil and crops grown, included the run off curve numbers (Appendix C). EPIC was adjusted so crop yields for each soil type were representative of current crop production for the study area (Appendix D).

The EPIC model was simulated 25 years for each crop. The 25 year simulation period was recommended by Putman and Dyke (1987), to allow the model to stabilize and provide more accurate results. Simulations were made for each crop rotation, soil type, tillage practice, and fertilizer restriction level.

Output information from EPIC which was used in the analysis, included yield and nitrogen leaching relationships with nitrogen fertilizer restrictions. Utilizing yield information provided by EPIC, combined with the crop budget information previously estimated, net revenues for each rotation, soil type, crop rotation, tillage practice, and fertilizer application level was calculated. Crop yield, nitrate leaching, and net revenue by rotation for each soil type and tillage practice are presented in Appendix E. The net revenues estimated, however, did not capture the effect of agricultural commodity programs.

Adler, Collins, and Loring soils were most conducive to crop production activity. Corn yields were greatest on the

Adler soil type. Soybean production was the greatest on Collins and Adler soils, while Loring soil allowed for the greatest wheat yield. The poorest land for crop production included the Waverly, Memphis, Falaya, and Convent Soils. Corn production was the least on Waverly soils while Memphis had the smallest soybean yield. Wheat yields were the smallest on the Falaya and Convent soils.

Nitrate leaching varied by soil type, tillage practice, crop rotation and fertilizer application level. Memphis, Lexington and Calloway soils provided a subsurface medium which allowed the greatest amount of nitrate leaching. The continuous soybean crop rotation was conducive to the greatest amount of leaching. The ability of the soybean crop to fix nitrogen increased the nitrate levels in the soil and allowed for increased nitrate leaching potential.

Crop rotations had a significant impact on individual crop yield adjustments in response to the levels of applied fertilizer. Rotations which included the soybean crop had smaller reductions in yields, as field applied nitrogen fertilizer was restricted. Nitrogen provided to the soil from the soybean plant compensated for the reduction in field applied nitrogen fertilizer.

Net revenue was also impacted by reductions in nitrogen fertilizer. The largest reduction in net revenue occurred for the continuous crop rotations, with the exception of soybeans. Net revenue increased from the base for several of the

nitrogen fertilizer restriction scenarios. The reduction in total production costs as a result of less nitrogen fertilizer, offsets the loss in total revenue resulting from decreased yields. This was particularly pronounced for rotations which included soybean production. The results indicate that nitrogen fertilizer was applied in excess of that required for profit maximization for the three county study area.

Agricultural Economic Impacts

Incorporating net revenue, yields, nitrate leaching, and yield responses, into the linear programming model allowed the estimation of a maximum net revenue combination of crop production activities, tillage practices, and nitrogen fertilizer application volumes. Corn, soybeans and wheat were constrained as lower limits, representing the 1985-1989 average level of production. The crop production values used for the region were 16,876,811 bushels for corn, 11,772,886 bushels for soybeans, and 6,579,141 bushels for wheat (Tennessee Department of Agriculture, 1989). The constrained production of grain crops was incorporated into the model to force the region to continue to meet the typical crop demands for the region. Grain purchasing activities were included to allow demand to be met if production became unfeasible as a result of imposed fertilizer restrictions. The purchases were

subtracted from net revenue in the region. Several scenario simulations were made using the linear programming model. The first was to estimate a base solution. Constraints were not imposed on fertilizer or nitrate leaching for the base net revenue maximization level. The optimal mix of crops, appropriate tillage practices and the volume of nitrogen fertilizer use were identified in the base solution.

Analysis related to imposing restrictions on the availability of nitrogen fertilizer was conducted after the base solution was established. Total nitrogen fertilizer availability and leaching volumes for the region were constrained from the base scenario, in 10 percent reduction increments. The linear programming model then selected the most profitable enterprises with the imposed constraints.

Corn, soybean and wheat production for the base solution were 17,876,811 bushels, 11,772,886 bushels, and 6,579,141 bushels respectively (Table 3). Corn production decreased approximately 10 percent from the base as nitrogen fertilizer availability was reduced by 90 percent. Soybean production decreased five percent and wheat production decreased approximately 15 percent when comparing the two extreme solutions, the baseline and the 90 percent reduction scenario. Hay did not enter the solution under any of the alternative scenarios. Grain purchases also did not occur under any of the scenarios.

Available acreages for each soil type were fully utilized

Table 3. Production, Net Revenue and Leaching Response to Total Nitrogen Fertilizer Restriction Scenarios.

Variable	Units	Percent of Base Total Nitrogen Fertilizer Availability									
		Base	90 %	80 %	70 %	60 %	50 %	40 %	30 %	20 %	10 %
Net Revenue	000 dol	59,210	59,036	58,754	58,383	57,720	56,885	55,877	54,759	53,344	51,838
Leaching	000 lbs	897	808	718	628	449	359	359	269	179	90
Fertilizer applied	000 lbs	14,361	12,925	11,489	10,053	8,617	7,181	5,745	4,308	2,872	1,436
Corn Production	000 bu.	16,876	16,940	16,970	16,956	16,893	16,626	16,480	16,117	15,768	15,369
Soybean production	000 bu.	11,772	11,699	11,629	11,561	11,492	11,453	11,384	11,294	11,225	11,157
Wheat production	000 bu.	6,579	6,521	6,449	6,378	6,293	6,249	6,094	5,990	5,863	5,742
Hay production	000 bu.	0	0	0	0	0	0	0	0	0	0
Corn Purchase	000 bu.	0	0	0	0	0	0	0	0	0	0
Soybean Purchase	000 bu.	0	0	0	0	0	0	0	0	0	0
Wheat purchase	000 bu.	0	0	0	0	0	0	0	0	0	0

under all scenarios, except for the Memphis soil with a 12 percent slope. The Memphis soil type did not enter the solution when regional fertilizer availability was restricted to levels greater than 70 percent of the base (Table 4).

Crop rotation, soil, and tillage practice activity response to restricting the availability of nitrogen fertilizer are presented in Table 5. The majority of cropped acres were in a corn-soybean-wheat/soybean rotation. Corn-soybean and continuous soybean rotations were implemented on a portion of the Birds soil. The Memphis soil, with a 12 percent slope, was the only soil type which utilized a continuous corn rotation. The Waverly soil type had both continuous soybean and corn-soybean rotation activities enter into the solutions. Conventional tillage practices dominated almost exclusively the cropland acreages. Waverly was the only soil which utilized a conservation tillage practice. Yield response and nitrate leaching characteristics allowed the conservation tillage practice to enter into the solution after total nitrogen fertilizer availability was restricted to levels greater than 50 percent of the base.

General economic impacts for the region from reducing available nitrogen fertilizer were not as substantial as expected. Yield stability (as indicated from the EPIC results) under various crop rotations partly explains the economic results. Crop rotations including soybeans, which produce nitrogen, allowed yields as estimated by the EPIC

Table 4. Acreages Utilized by Soil Type For Different Fertilizer Use Reduction Scenarios.

Soil	Slope	Percentage of Base Fertilizer Applied									
		Base	90	80	70	60	50	40	30	20	10
		acres									
Grenada	3 X	45,805	45,805	45,805	45,805	45,805	45,805	45,805	45,805	45,805	45,805
Grenada	7 X	27,577	27,577	27,577	27,577	27,577	27,577	27,577	27,577	27,577	27,577
Loring	3 X	58,892	58,892	58,892	58,892	58,892	58,892	58,892	58,892	58,892	58,892
Loring	6 X	28,511	28,511	28,511	28,511	28,511	28,511	28,511	28,511	28,511	28,511
Loring	10 X	21,500	21,500	21,500	21,500	21,500	21,500	21,500	21,500	21,500	21,500
Falaya	2 X	78,991	78,991	78,991	78,991	78,991	78,991	78,991	78,991	78,991	78,991
Waverly	2 X	36,457	36,457	36,457	36,457	36,457	36,457	36,457	36,457	36,457	36,457
Adler	2 X	8,881	8,881	8,881	8,881	8,881	8,881	8,881	8,881	8,881	8,881
Lexington	5 X	4,207	4,207	4,207	4,207	4,207	4,207	4,207	4,207	4,207	4,207
Lexington	12 X	2,804	2,804	2,804	2,804	2,804	2,804	2,804	2,804	2,804	2,804
Collins	2 X	59,360	59,360	59,360	59,360	59,360	59,360	59,360	59,360	59,360	59,360
Convent	2 X	3,739	3,739	3,739	3,739	3,739	3,739	3,739	3,739	3,739	3,739
Calloway	1 X	10,750	10,750	10,750	10,750	10,750	10,750	10,750	10,750	10,750	10,750
Calloway	4 X	27,577	27,577	27,577	27,577	27,577	27,577	27,577	27,577	27,577	27,577
Memphis	3 X	13,555	13,555	13,555	13,555	13,555	13,555	13,555	13,555	13,555	13,555
Memphis	6 X	12,152	12,152	12,152	12,152	12,152	12,152	12,152	12,152	12,152	12,152
Memphis	12 X	2,804	2,804	2,804	2,804	2,804	0	0	0	0	0
Birds	1 X	5,609	5,609	5,609	5,609	5,609	5,609	5,609	5,609	5,609	5,609
Providence	6 X	18,229	18,229	18,229	18,229	18,229	18,229	18,229	18,229	18,229	18,229

Table 5. Acreage Distribution by Soil, Crop Rotation, Tillage Practice, and Nitrogen Application Rate for the 10 Scenarios of Total Fertilizer Availability.

Soil	Slope	Rotation	Crop	Rotation	Tillage Practice	Percent of Total Regional Nitrogen Fertilizer Available for Use.....										
						Base	90	80	70	60	50	40	30	20	10	
						acres.....										
pct.																
Adler	2	C-S-W/S	40		Conventional	8,881	8,881	8,881	8,881	8,881	8,881	8,881	8,881	8,881	8,881	8,881
Adler	2	C-S-W/S	20		Conventional											
Birds	1	S	--		Conventional	5,609	1,503									
Birds	1	C-S	40		Conventional		4,079	5,609								
Birds	1	C-S	20		Conventional				5,609	5,609						
Birds	1	C-S	0		Conventional											
Calloway	1	C-S-W/S	40		Conventional	10,760	10,750									
Calloway	1	C-S-W/S	20		Conventional											
Calloway	1	C-S-W/S	0		Conventional											
Calloway	4	C-S-W/S	40		Conventional	27,576	4,309									
Calloway	4	C-S-W/S	0		Conventional		23,268	27,576								
Collins	2	C-S-W/S	60		Conventional	59,360	59,360	59,360	59,360	59,360						
Collins	2	C-S-W/S	40		Conventional											
Collins	2	C-S-W/S	20		Conventional											
Collins	2	C-S-W/S	0		Conventional											
Convent	2	C-S-W/S	80		Conventional	3,739	3,739	3,739								
Convent	2	C-S-W/S	60		Conventional											
Convent	2	C-S-W/S	40		Conventional											
Convent	2	C-S-W/S	20		Conventional											
Convent	2	C-S-W/S	0		Conventional											
Falaya	2	C-S-W/S	80		Conventional	78,991	78,991	78,991	78,991							
Falaya	2	C-S-W/S	60		Conventional											
Falaya	2	C-S-W/S	40		Conventional											
Falaya	2	C-S-W/S	20		Conventional											
Falaya	2	C-S-W/S	0		Conventional											
Grenada	3	C-S-W/S	40		Conventional	45,805	45,805	45,805	45,805	45,805						
Grenada	3	C-S-W/S	0		Conventional											
Grenada	7	C-S-W/S	60		Conventional	27,577	27,577	27,577	27,577	27,577						
Grenada	7	C-S-W/S	40		Conventional											
Grenada	7	C-S-W/S	0		Conventional											
Loring	3	C-S-W/S	40		Conventional	58,892	58,892	58,892	58,892	58,892						
Loring	3	C-S-W/S	20		Conventional											
Loring	3	C-S-W/S	0		Conventional											
Loring	6	C-S-W/S	60		Conventional	28,511	28,511	4,048								

Table 5. Continued

Soil	Slope	Crop Rotation	Percent of Base Nitrogen Used per Rotation	Tillage Practice	Percent of Total Regional Nitrogen Fertilizer Available for Use.....										
					Base	90	80	70	60	50	40	30	20	10	
					acres.....										
pct.															
Loring	6	C-S-W/S	40	Conventional			24,463	28,511	28,511	18,008		28,511	28,511	28,511	
Loring	6	C-S-W/S	20	Conventional						10,503	28,511				
Loring	10	C-S-W/S	80	Conventional	21,500	21,500									
Loring	10	C-S-W/S	60	Conventional			21,500								
Loring	10	C-S-W/S	40	Conventional				21,500	21,500	11,891					
Loring	10	C-S-W/S	20	Conventional	4,207	4,207	4,207	4,207	4,207	4,207	9,609	21,500	21,500	21,500	
Lexington	5	C-S-W/S	20	Conventional											
Lexington	5	C-S-W/S	0	Conventional											
Lexington	12	C-S-W/S	20	Conventional	2,804	2,804	2,804	2,804	2,804	2,804	2,804	2,804	2,804	2,804	
Lexington	12	C-S-W/S	0	Conventional											
Memphis	3	C-S-W/S	60	Conventional	13,555	13,555	13,555	13,555	13,555	13,555					
Memphis	3	C-S-W/S	40	Conventional											
Memphis	3	C-S-W/S	20	Conventional	12,152	12,152	12,152	941							
Memphis	6	C-S-W/S	40	Conventional				11,211	12,152	12,152	12,152	12,152	12,152	12,152	
Memphis	6	C-S-W/S	20	Conventional											
Memphis	6	C-S-W/S	0	Conventional	2,804	2,804	2,804	2,804	2,804	2,804					
Memphis	12	C	60	Conventional											
Memphis	12	C-S	40	Conventional	18,229	18,229	18,229	18,229	18,229	2,804	2,804				
Providence	6	C-S-W/S	40	Conventional											
Providence	6	C-S-W/S	20	Conventional											
Waverly	2	S	--	Conventional	36,457	36,457	33,786	29,513	25,240	18,229	18,229	18,229	18,229	18,229	
Waverly	2	C-S	60	Conventional			2,671	6,944		21,367	17,084	12,820	8,547	4,273	
Waverly	2	C-S	40	Conventional											
Waverly	2	C-S	0	Conservation					11,217	15,090	19,373	23,637	27,910	32,184	

^a C Continuous Corn rotation

C-S Corn-Soybean rotation

C-S-W/S Corn-Soybean-Wheat/Soybean rotation

S Continuous Soybean rotation

model to remain more stable and as a result lessened the economic impacts to agriculture.

A dynamic analysis of achieving the most cost efficient method to obtain water quality will be discussed in Chapter 5. Information obtained from the linear programming model along with nitrate leaching information will be incorporated into the optimal control model.

CHAPTER V

OPTIMAL DYNAMIC STRATEGIES

Optimal Control Model

A dynamic modeling system was established for use in analyzing potential economic and ecological imbalances of the nitrate contamination of ground water. Economic and physical characteristics of the nitrate contamination problem were the two major components included in the modeling system. Economic information included financial costs associated with prevention policies (the cost imposed on agriculture from restricting the use of nitrogen fertilizer), and the cost of removing nitrates from ground water. The leaching process of nitrates to ground water supplies were included in the modeling system to capture the physical characteristics associated with the contamination problem.

Adjustments in net revenue, as a result of reducing available nitrogen fertilizer, were used to estimate the economic costs imposed on the agricultural industry (net revenues were obtained from results generated by the linear programming model in chapter IV). A loss function representing the economic impacts to agriculture was obtained by mapping the changes in net revenue which resulted from restricting available nitrogen fertilizer. Utilizing

production economic theory and the previously determined changes in net revenue, a quadratic loss function was used to represent the costs to agriculture. The loss function was represented by equation 1.

$$A(N_t) = a - bN_t + cN_t^2 \quad (eq. 1)$$

Where:

$A(N_t)$ is the loss function for agriculture resulting from a reduction in regional nitrogen fertilizer applications (dollars/t);

N_t is the total amount of nitrogen fertilizer (lbs. of nitrogen fertilizer/t) available to the region (control variable); and

a , b , and c are the net revenue loss parameter values.

Nitrate removal costs were a function of the density of nitrates in the ground water at point of use. The cost function for removing nitrates from water was represented by an upward sloping quadratic function (Wright, 1974). The costs associated with removing nitrates, therefore, increase at an increasing rate as the ground water becomes more contaminated. Nitrate removal costs were represented by equation 2.

$$H(D_t) = \frac{a}{2} D_t^2 \quad (eq. 2)$$

Where:

$H(D_t)$ is the financial cost of removing nitrate at point of use from the ground water (dollars/gallon);

D_t is the nitrate concentration in the ground water (lbs. of nitrate/gallon of water); and

α is the nitrate removal cost parameter value.

Nitrogen fertilizer applied to the surface of fields was the control variable in the analysis. Dynamics of the nitrate contamination of ground water consisted of leaching, dispersion or diffusion, and fresh water recharge. The application of fertilizer was assumed to be linearly related to nitrate leaching as was indicated from research by Broadbent and Rauschkolb (1977). Field applied nitrogen fertilizer and nitrate leaching relationships were represented by equation 3.

$$L(N_t) = nN_t \quad (\text{eq. 3})$$

Where:

$L(N_t)$ is the total amount of nitrates leaching to the ground water (lbs. of nitrate/t);

N_t is the total amount of nitrogen fertilizer (lbs. of nitrogen fertilizer/t) applied to the region (control variable); and

n is the nitrate leaching parameter value.

Nitrate concentrations in the ground water were assumed to be related to the volume of water in the aquifer and the amount of fresh water recharge. Leached nitrates $L(N_t)$ were

multiplied by the inverse of the volume of ground water¹⁴ (Z_t) (1/millions of gallons) to obtain a nitrate concentration level. The influx of non-contaminated water recharge reduced the concentration level of nitrates in ground water. A linear function was used to represent the effects of recharge on the nitrate concentration levels in the ground water¹⁵ (Equation 4).

$$R(D_t) = \delta D_t \quad (eq\ 4)$$

Where:

$R(D_t)$ is the rate at which nitrate density in the ground water decreased due to recharge (lbs./gallon/t);

D_t is the nitrate concentration in the ground water (lbs. of nitrate/gallon of water); and

δ is the recharge parameter value.

The general dynamics of the contamination of ground water from nitrates were governed by equation 5.

$$\dot{D}_t = L(N_t) + Z - R(D_t) \quad (eq. 5)$$

¹⁴ The inverse of total volume of ground water was used to simplify the mathematical procedures involved in the dynamic analysis. Z_t will be referred to in the remainder of the text as ground water volume.

¹⁵ A reduction in nitrate concentrations as a result of freshwater recharge was a linear function of the initial contamination levels. A 20 percent fresh water inflow would result in the nitrate concentration being reduced by 20 percent.

Where:

$\dot{D}_t$ is the dynamics of the nitrate concentration in ground water; and

Z is the inverse of the ground water volume (1/millions of gallons).

The problem confronting the region was to select the cost minimizing level of nitrogen fertilizer application which would result in the economically optimum level of nitrate contamination of ground water and removal at point of use over time. Decisions made at any point in time regarding the nitrogen fertilizer application level influenced the rate at which nitrates were being accumulated in ground water and the associated cost of removing nitrates at point of use. Minimizing the regional cost of achieving point of use ground water quality over time through selection of the appropriate levels of nitrogen fertilizer may be represented by equation 6, the objective functional.

$$MinJ(N_t, D_t) = \int_{t=0}^{\infty} e^{-rt} [A(N_t) + H(D_t) * Y] dt \quad (eq. 6)$$

Where:

r is the discount rate;

t is time; and

Y is yearly volume of water consumption (gallons/t).

The objective functional consisted of the economic costs

(loses) imposed on the agricultural industry $A(N_t)$, a function of the amount of nitrogen fertilizer applied, and costs associated with removal of the nitrate from ground water at point of use $H(D_t)$, a function of nitrate density at a given point in time. Volume of water used in the region per year (Y) was multiplied by $H(D_t)$ to obtain the total cost of removing nitrates from ground water at point of use.

The first step toward obtaining an optimal control solution was to define the Hamiltonian, which was established by combining equations 5 and 6. The Hamiltonian represented the total contribution to the cost of decisions regarding nitrogen applications in a single period if the rate at which costs were accumulated in each period were minimized. Equation 7 represents the current value Hamiltonian.

$$H^c = [A(N_t) + H(D_t) * Y] + \lambda [L(N_t) * Z - R(D_t)] \quad (eq. 7)$$

Three first order pontryagin conditions were established from the Hamiltonian equation. The first pontryagin condition was represented by equation 8.

$$\frac{\partial H^c}{\partial N} = A'(N_t) + \lambda ZL'(N_t) = 0 \quad (eq 8)$$

Where

$$\begin{aligned} A'(N_t) &< 0 \\ A''(N_t) &> 0 \end{aligned}$$

Economic interpretation of the first and second order derivative (' denotes differentiation) of $A(N_t)$ implied that as nitrogen increased, the financial loss to agriculture decreased. Field applied nitrogen fertilizer was a benefit to farm operators in the production process. Thus, $A'(N_t)$ may be interpreted as the marginal reduction in loss (or benefit to agriculture) from increasing nitrogen fertilizer use per unit.

The variable λ may be interpreted as the marginal damage (cost) associated with the per unit nitrate concentration in ground water. $ZL'(N_t)$ represented the rate of change of nitrate concentration associated with a unit change in the control. The interpretation of $\lambda ZL'(N_t)$ was the marginal damage (cost) associated with increasing per unit nitrogen fertilizer use. Equation 8, therefore, implied that the marginal positive effect (benefit) of changing nitrogen fertilizer application must offset the negative (damage) effect on the total cost of achieving point of use water quality in the next period.

The second pontryagin condition was represented by equation 9.

$$\dot{\lambda} = r\lambda - \frac{\partial H^c}{\partial D_t} = r\lambda - [YH'(D_t) - \lambda R'(D_t)] \quad (\text{eq. 9})$$

For purposes of interpretation, equation 9 can be rewritten to present value form. The present value Hamiltonian (H^{PV}) may be obtained by multiplying through the

current value Hamiltonian by e^{-rt} . The present value Hamiltonian was represented as equation 9a.

$$-\dot{\lambda} = \frac{\partial H^c}{\partial D_t} = [YH'(D_t) - \lambda R'(D_t)] \quad (\text{eq. 9a})$$

$-\dot{\lambda}$ may be interpreted as the rate of depreciation of the marginal present cost of an increment in nitrate concentration, λ . $YH'(D_t)$ was the marginal cost of clean up per unit of change in the nitrate density of ground water. $R'(D_t)$ was the marginal value of the resulting decrease in costs attributed to ground water recharge. The right hand side of the equation was the change in cost from a unit change in nitrate concentration. Hence, equation 9a requires that the marginal present value of losses must depreciate over time at the sum of the rates at which an incremental increase in nitrate contamination, D , contributes to clean up costs and the value of decreasing contamination through recharge.

The third pontryagin condition is the equation of motion and was represented by equation 10.

$$\frac{\partial H^c}{\partial \lambda} = ZL(N_t) - R(D_t) \quad (\text{eq. 10})$$

A summary of the functional forms of the equations along with the respective derivatives are presented in equations 11,

12, 13, and 14.

$$L(N_t) = nN_t \quad L'(N_t) = n \quad L''(N_t) = 0 \quad (eq. 11)$$

$$H(D_t) = \frac{\alpha}{2} D_t^2 \quad H'(D_t) = \alpha D_t \quad H''(D_t) = \alpha \quad (eq. 12)$$

$$A(N_t) = a - bN_t + CN_t^2 \quad A'(N_t) = -b + 2CN_t \quad A''(N_t) = 2C \quad (eq. 13)$$

$$R(D_t) = \delta D_t \quad R'(D_t) = \delta \quad R''(D_t) = 0 \quad (eq. 14)$$

Identification of the isoclines was the first step toward developing a phase diagram of the system. The two isoclines which were derived were $\dot{N}_t = 0$, and $\dot{D}_t = 0$. The $\dot{N}_t = 0$ isocline represented the combination of N and D which held the application of nitrogen constant over time. The $\dot{D}_t = 0$ isocline was the combination of N and D which held nitrate concentrations constant over time.

$\dot{N}_t = 0$ Isocline

The $\dot{N}_t = 0$ isocline was derived utilizing the first order pontryagin conditions. Rewriting and solving the first pontryagin condition (equation 8) for λ , equation 15 was obtained.

$$\begin{aligned} \lambda ZL'(N_t) &= -A'(N_t) \\ \lambda &= -A'(N_t)/ZL'(N_t) \end{aligned} \quad (eq.15)$$

The time derivative of λ was taken resulting in the following.

$$\dot{\lambda} = - \frac{ZL'(N_t) * A''(N_t) \frac{dN}{dt} - ZA'(N_t) * L''(N_t) \frac{dN}{dt}}{[ZL'(N_t)]^2}$$

The Z s were canceled.

$$\dot{\lambda} = - \frac{[L'(N_t) * A''(N_t)] \dot{N}_t - [A'(N_t) * L''(N_t)] \dot{N}_t}{Z[L'(N_t)]^2}$$

The $\dot{N}_t$ was factored out.

$$\dot{\lambda} = - \frac{[L'(N_t) * A''(N_t) - A'(N_t) * L''(N_t)] \dot{N}_t}{Z[L'(N_t)]^2}$$

$\dot{\lambda}$ and λ were substituted into the second pontryagin condition (equation 9) resulting in equation 16.

$$\frac{-L'(N_t) * A''(N_t) - A'(N_t) * L''(N_t)] \dot{N}_t}{Z[L'(N_t)]^2} = \frac{[r + R'(D_t)] * [-A'(N_t)] - YH'(D_t)}{Z[L'(N_t)]^2} \quad (eq.16)$$

The derivatives were then signed, common terms canceled and equation 16 was rewritten based on the following.

- a) Negative signs cancel.
- b) Since $L''(N_t) = 0$ the second half of left hand side of the equation drops out.

- c) The left hand side ($L'(N_t)$) cancels with the denominator.
- d) Based on a-c above, equation 16 may be written as follows:

$$\left[\frac{A''(N_t)}{ZL'(N_t)} \right] \dot{N}_t = \frac{[r+R'(D_t)] * [A'(N_t)]}{ZL'(N_t)} + YH'(D_t)$$

The above equation was multiplied through by $ZL'(N_t)$.

$$A''(N_t) \dot{N}_t = [r+R'(D_t)] * A'(N_t) + YH'(D_t) * ZL'(N_t)$$

The above equation was then solved for $\dot{N}_t$ to obtain a first order difference equation (equation 17).

$$\dot{N}_t = \frac{[r+R'(D_t)] * A'(N_t) + YH'(D_t) * ZL'(N_t)}{A''(N_t)} \quad (eq. 17)$$

$\dot{N}_t$ was set equal to 0.

$$\dot{N}_t = [r+R'(D_t)] * A'(N_t) + YH'(D_t) * ZL'(N_t) = 0 \quad (eq. 18)$$

The functional forms previously expressed in equations 11-14 were substituted into equation 18.

$$[r+\delta] * [-b+2CN_t] + Y[\alpha D_t] * Z * n = 0$$

Multiplied out were $(r + \delta) * (2CN_t)$ and $(r + \delta) * (-b)$.

$$2(r+\delta)CN_t + (-b)(r+\delta) + Y[\alpha D_t]Zn$$

$$2(r+\delta)CN_t = -Y[\alpha D_t]Zn + b(r+\delta)$$

N_t was solved for.

$$N_t |_{\dot{N}_t=0} = \frac{b(r+\delta)}{2(r+\delta)C} - \frac{YZ\alpha n}{2(r+\delta)C} D_t$$

The previous equation was rewritten to obtain the $\dot{N}_t = 0$ isocline (eq 19).

$$N_t |_{\dot{N}_t=0} = \frac{b}{2C} - \frac{YZ\alpha n}{2(r+\delta)C} D_t \quad (eq. 19)$$

$\dot{D}_t = 0$ Isocline

The equation of motion was identified from the 3rd pontryagin condition (equation 10).

$$\dot{D}_t = ZL(N_t) - R(D_t)$$

Functional forms (equation 11-14) were substituted in and the equation was set equal to zero to obtain the following:

$$ZnN_t - \delta D_t = 0$$

The $\dot{D}_t = 0$ isocline (equation 20) was obtained by solving the above for N_t .

$$ZnN_t = \delta D_t$$

$$N_t|_{\dot{D}_t=0} = \frac{\delta D_t}{Zn} \quad (\text{eq. 20})$$

A graphical illustration of the isoclines are presented in Figure 7. The $\dot{N}_t = 0$ isocline had a positive slope while the $\dot{D}_t = 0$ isocline had a downward slope.

Steady State

The steady state for the optimal control model identifies that point at which the system is at rest. At the steady state there is no growth in N or D . A balance exists between the amount of fertilizer applied, the nitrate stock in the ground water aquifer and the amount of nitrate removal occurring. The steady state point may be represented graphically at the intersection of the two isoclines (Figure 7). The steady state may be mathematically derived by equating the two isoclines (equations 19 and 20) and solving for D_t and N_t . The steady state for D was represented by equation 21.

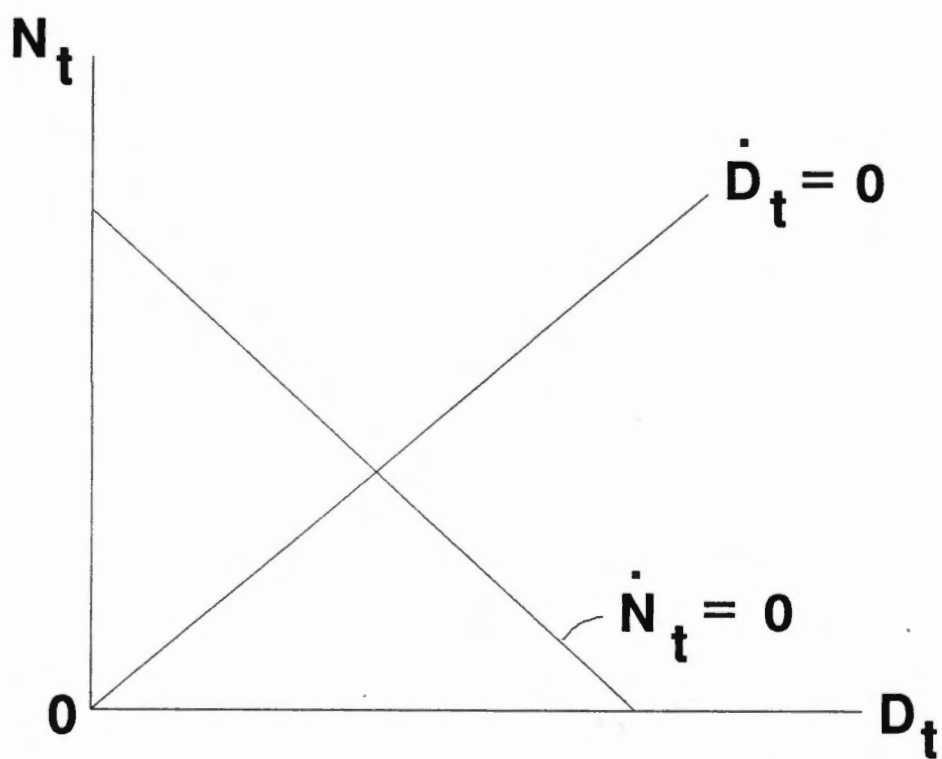


Figure 7. Representative Isoclines for the Optimal Control System.

$$\frac{\delta}{Zn} D_t = \frac{b}{2C} - \frac{YZ\alpha n}{2(r+\delta)} D_t$$

*Solve For D_t^**

$$\frac{\delta}{Zn} D_t + \frac{YZ\alpha n}{2(r+\delta)} D_t = \frac{b}{2C}$$

$$D_t \left[\frac{\delta}{Zn} + \frac{YZ\alpha n}{2(r+\delta)} \right] = \frac{b}{2C}$$

$$D_t^* = \frac{\frac{b}{2C}}{\frac{\delta}{Zn} + \frac{YZ\alpha n}{2(r+\delta)}} \quad \text{Steady State} \quad (\text{eq. 21})$$

The steady state for N was represented by equation 22.

$$\text{Substitute } D_t^* \text{ into } N_t | \dot{D}_{t=0} = \frac{\delta D_t}{Zn}$$

$$N_t^* = \frac{\delta}{Zn} * \frac{\frac{b}{2C}}{\frac{\delta}{Zn} + \frac{YZ\alpha n}{2(r+\delta)}} \quad \text{Steady State} \quad (\text{eq. 22})$$

The steady state solutions were characterized as a minimum when the second partial derivative of the Hamiltonian (equation 7) with respect to N and D was positive definite when evaluated at N^* and D^* . The first principal minor of the Hessian matrix must be positive:

$$H_{NN} = A''(N_t) + LH''(D_t) > 0$$

The Hessian was positive definite.

$$\begin{bmatrix} H_{NN} & H_{ND} \\ H_{DN} & H_{DD} \end{bmatrix} = A''(N_t) + YH''(D_t) > 0$$

Characterization of The System

Once the steady state had been determined the direction of motion for the system was characterized. The partial derivative of equation 17 with respect to D_t was taken and equation 23 was derived. The sign for the equation was positive.

$$\frac{\partial \dot{N}_t}{\partial D_t} \Big|_{N=\bar{N}} = \frac{[A'(N_t) * R''(D_t)] + [YZL'(N_t) * H''(D_t)]}{A''(N_t)} > 0 \quad (eq. 23)$$

$$\begin{aligned} A'(N_t) &< 0 \\ A''(N_t) &> 0 \\ R''(D_t) &= 0 \\ YZL'(N_t) &> 0 \\ H''(D_t) &> 0 \end{aligned}$$

The partial derivative of the first difference equation (equation 6) was taken and signed to obtain equation 24.

$$\dot{D} = ZL(N_t) - R(D_t)$$

$$\frac{\partial \dot{D}_t}{\partial N_t} \Big|_{D=\bar{D}} = ZL'(N_t) > 0 \quad (eq. 24)$$

A characterization of the direction of motion for the system of equations was obtained by examining the signs of

equation 23 and 24. A schematic representation of the motion of the system is presented in Figure 8. The figure was divided into four quadrants.

Characterization of quadrant I. Nitrate concentrations over time increase and clean up costs for point of use ground water becomes greater. Nitrogen fertilizer availability decreases below the $\dot{N}_t = 0$ isocline, imposing potential losses on the agricultural industry. Above the $\dot{N}_t = 0$ isocline, optimal nitrogen fertilizer availability would increase. The economic and physical characteristics of the optimal paths portrays an increased contamination of ground water from agricultural nitrogen fertilizer. Consumers have the burden of removing nitrate contamination from the ground water.

Characterization of quadrant II. Nitrogen fertilizer availability over time increases reducing potential financial losses to agriculture. Nitrate concentrations in the ground water decreases below the $\dot{D}_t = 0$ isocline, while increasing above the $\dot{D}_t = 0$ isocline. The optimal paths move in a direction would put the burden of obtaining clean water on the consumer, through use of nitrate removal systems, while allowing agriculture to contaminate the ground water.

Characterization of quadrant III. Nitrate concentrations decrease over time, implying reduced costs to consumers for

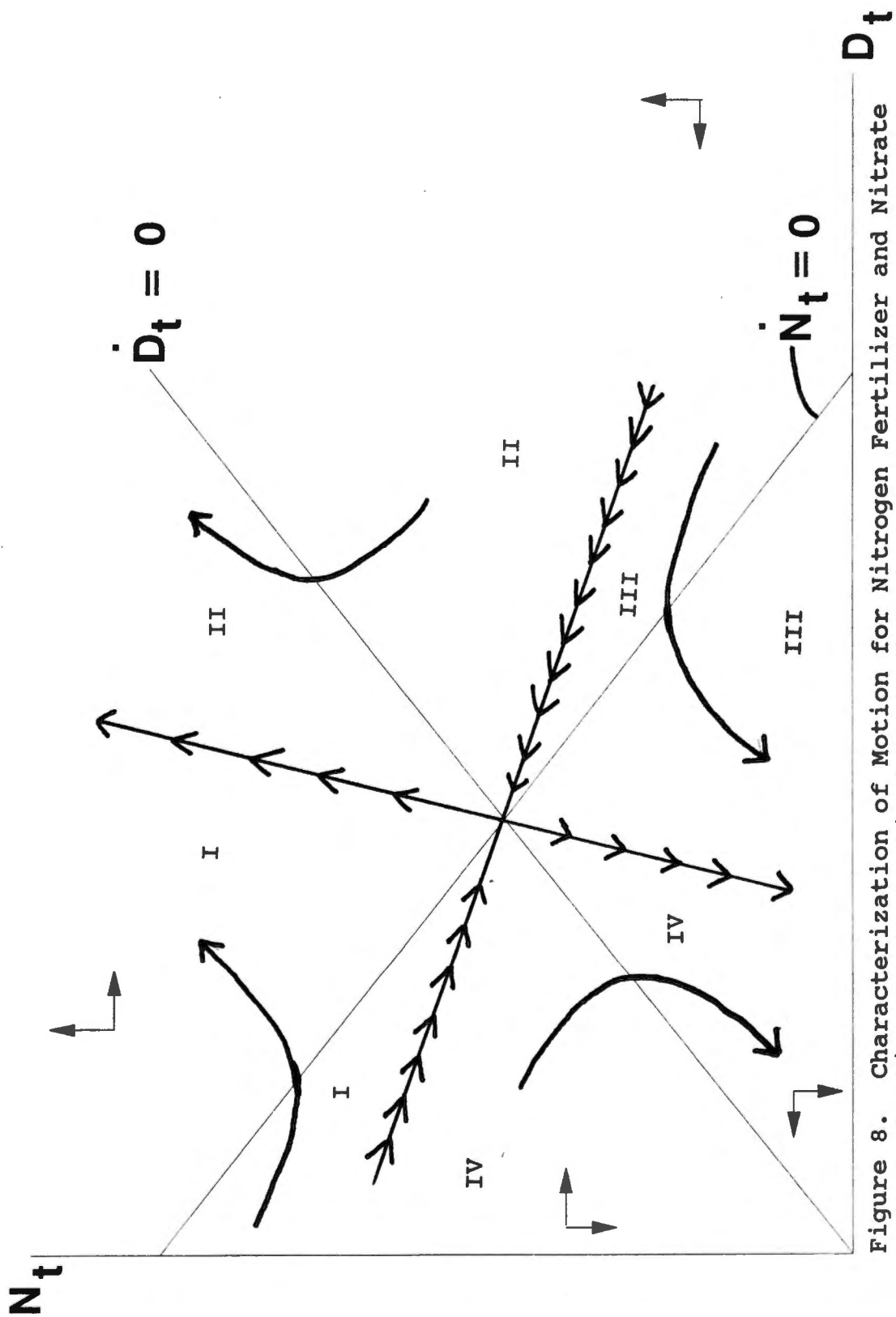


Figure 8. Characterization of Motion for Nitrogen Fertilizer and Nitrate Concentration for the Optimal Control System.

clean up. Nitrogen fertilizer availability increases above the $\dot{N}_t = 0$ isocline reducing losses to agriculture. Availability of nitrogen fertilizer decreases to the left of the $\dot{N}_t = 0$ isocline implying increased financial losses to agriculture. The optimal paths result in a reduction in ground water nitrate concentration levels.

Characterization of quadrant IV. Nitrogen fertilizer availability becomes less over time in this area of Figure 8. Above the $\dot{D}_t = 0$ isocline the nitrate concentration levels increase. Below the $\dot{D}_t = 0$ the nitrate concentration level decreases. The optimal paths portray a reduction in nitrogen fertilizer availability increasing the financial cost imposed on agriculture.

Stability

The stability of the steady state was examined after characterizing the motion of the system. Previously developed were two first order linear homogenous equations from which the steady state was identified. The following is a summary of the first order linear difference equations.

$$\dot{N}_t = \frac{[r+R'(D_t)] * A'(N_t) + YH'(D_t) * ZL'(N_t)}{A''(N_t)}$$

Substitute in the Functional Forms

$$\dot{N}_t = \frac{(r+\delta)(-b+2CN_t) + ZYanD_t}{2C} \quad (eq. 25)$$

$$\dot{D}_t = L(N_t)Z - R(D_t)$$

Substitute in the Functional Form

$$\dot{D}_t = ZnN_t - \delta D_t \quad (eq. 26)$$

A linearized local stability test of the steady state was conducted utilizing equations 26 and 27. The first step to linearize the system around the equilibrium or steady state point, was to develop a Taylor Series expansion.

$$\begin{bmatrix} \dot{N}_t \\ \dot{D}_t \end{bmatrix} = \begin{bmatrix} \frac{\partial \dot{N}}{\partial N_t} - \mu & \frac{\partial \dot{N}}{\partial D_t} \\ \frac{\partial \dot{D}}{\partial N_t} & \frac{\partial \dot{D}}{\partial D_t} - \mu \end{bmatrix} \begin{bmatrix} N_t \\ D_t \end{bmatrix} + \sigma(ND) = 0$$

Deriving the first order condition for the system the following was obtained.

$$\begin{aligned}
\frac{\partial \dot{N}}{\partial N} &= \frac{2C(r+\delta)}{2C} = (r+\delta) \\
\frac{\partial \dot{N}}{\partial D} &= \frac{ZY\alpha n}{2C} \\
\frac{\partial \dot{D}}{\partial N} &= ZN \\
\frac{\partial \dot{D}}{\partial D} &= -\alpha
\end{aligned}$$

From the first order conditions the Jacobian matrix (J) was developed and the determinant was established.

$$J = \begin{bmatrix} (r+\delta) & \frac{ZY\alpha n}{2C} \\ ZN & -\alpha \end{bmatrix}$$

$$\text{Determinant } D(J) = -\alpha(r+\delta) - \left(\frac{ZY\alpha n ZN}{2C} \right) < 0$$

Since the determinant was negative there was one positive root and one negative root. The steady state was therefore represented by a saddle point solution as illustrated in the phase diagram (Figure 8).

Estimation of Functional Forms

Parameter values of the functional forms used in the optimal control model were estimated. Regression techniques in combination with published data and numerical estimates derived from models in chapter IV were used to obtain the parameter values.

The loss function parameter values were based on findings from the linear programming model analysis discussed in chapter IV. The change in net revenue for the different scenarios were transformed to equational form through use of statistical regression methods. A quadratic loss function (equation 13) was estimated based on the changes in net revenue. The loss function along with the estimated coefficients are presented below.

$$A(N_t) = a - bN_t + cN_t^2 \quad R^2 = .99$$

9.09	1.255	.043	.01 level of significance
(.042)	(.012)	(.0007)	Standard error

Data for use in estimating the nitrate leaching function were obtained from the EPIC analysis discussed in Chapter IV. Fertilizer application-leaching relationships were derived on the assumption of linearity. The nitrate leaching equation was represented as follows:

$$L(N_t) = nN_t$$

.0625

Few studies were available which identified the costs associated with removing nitrate contamination from water supplies. The quadratic cost function (equation 12) was estimated with two nitrate removal cost points, provided from research by Guter (1982). The 1982 cost were adjusted to 1990 levels with the consumer price index (U.S. Department of Labor, 1990). The cost function along with the estimated coefficient is presented below.

$$H(D_t) = \frac{\alpha/2 * D_t}{1054.9231}$$

The estimated numerical value for the volume of water used in the region was based on per capita consumption. Volumes of per capita water consumption were 118.1 gallons/day, 51.9 gallons/day and 90 gallons/day for Weakly, Gibson, and Obion counties, respectively (Kerodle and Wilson, 1973). The per capita consumption volumes were multiplied by the respective county populations (Fig 4, Chapter III) and 365 (representing days in a year) to obtain a yearly consumption of 365.88 million gallons per year.

A representative recharge rate for the three county study area was established at 20 percent of the total ground water volume¹⁶ (U.S. Department of Interior, 1988; and Zurawski, 1978). The discount rate was established at a real rate of 4.8 percent.

Sensitivity Analysis

Parameter values associated with the leaching function (n), agriculture loss function (a, b, and C) water consumption (Y) and cost of nitrate removal represented the study area. The parameter value associated with aquifer size (Z), however, was unknown. The size of the aquifer is directly related to

¹⁶ Personal communication with Ann Hoos, U.S. Geological Survey, Nashville Tennessee, June, 1990.

the nitrate concentration level in the aquifer system. Thus, selection of the aquifer size defined the nitrate concentration level in the modeling system.

A sensitivity analysis was based on two different ground water volumes, resulting in two nitrate contamination levels. The first represented a steady state nitrate ground water contamination level which was less than the accepted standard (10 mg/l), and was defined as the no problem scenario (Table 6). The second volume of ground water chosen resulted in a steady state nitrate contamination level which was greater than the standard (16 mg/l) and was defined as the problem scenario (Table 6).

Utilizing the problem scenario, a steady state level of nitrate concentration and nitrogen fertilizer use level were determined. Examining the sensitivity of selected parameters in the optimal control model involved adjusting values which resulted in the nitrate contamination level decreasing from 16 mg/l to 8 mg/l. Results of the sensitivity analysis, including the associated costs to agriculture and to consumers for nitrate removal, are presented in Table 7.

The optimal control model was most sensitive to adjustments in the recharge rate and leaching parameters. A doubling of the recharge rate and a 50 percent reduction in the value of the leaching parameter resulted in the nitrate concentration level of the ground water to decrease to approximately 8 mg/l (the no problem scenario). Variations in

Table 6. Parameter Values, Nitrogen Fertilizer Applications, Nitrate Density, and Costs of Nitrate Removal for the No Problem and Problem Scenarios.

Parameter	Scenario.....	
	No Problem	Problem
b	1.25474	1.25474
C	0.04349	0.04349
δ	0.20000	0.20000
Z	0.00015	0.00030
n	0.06249	0.06249
Y	3658.88	3658.88
α	1054.92	1054.92
r	0.04800	0.04800
.....		
Solution Values		
Nitrogen Fertilizer	14.37 mill. lbs.	14.22 mill. lbs.
Nitrate Concentrations	8.1219 mg/l	16.0729 mg/l
Cost to Agriculture	\$36,710	\$38,370
Cost of Nitrate Removal	\$910,000	\$3,568,000

Table 7. Optimal Control Model Sensitivity to Parameter Adjustments Which Reduce Nitrate Concentration from 16 mg/l to 8 mg/l.

Parameter	Description	Parameter Value	Nitrate Concentration mg/l	Steady State Fertiliser Use mill. lbs.	Cost to Agriculture dollars	Cost of Nitrate Removal dollars
B	Coeff. for Loss Fn.	.6273711	8.03646	7.112	2,363,000	891,900
C	Coeff. for Loss Fn.	.0869812	8.03646	7.112	2,363,000	891,900
b	Recharge Rate	.40	8.119	14.369	36,730	910,400
n	Leaching Coeff.	.0312428	8.122	14.374	36,710	910,400
Y	Yearly Volume of Water mill. gal.	256.060	8.169	7.229	2,289,000	921,500
a	Nitrate Removal Coeff.	73844.62	8.169	7.228	2,290,000	921,500
r	Discount Rate	.144	16.136	14.279	37,530	3,596,000
r	Discount Rate	.0001	16.019	14.175	39,310	3,544,000
Base Problem Scenario				14.223	38,370	3,568,000

the yearly consumption of water as well as in the nitrate removal cost did not result in substantial changes in output from the dynamic model. A 70 fold increase in water consumption or in the cost of nitrate removal was required to change the ground water contamination level from 16 mg/l to 8 mg/l. Adjustments in the discount rate had a very small impact on the steady state nitrate ground water concentration level.

The costs imposed on agriculture and to consumers in relation to variations in parameter values are presented in Table 7. Agriculture costs at the steady state problem scenario were \$38,370, while the cost of nitrate removal was \$3,568,000. The balance over time between fertilizer application, hydrologic characteristics of the ground water aquifers, and nitrate removal at the tap resulted in consumers absorbing most of the cost. Agriculture was financially responsible for obtaining clean water only when the cost of filtering increased substantially or the population in the region was much larger (Table 7).

Optimal Ground Water Strategies

The problem scenario which resulted in a steady state nitrate concentration level above the acceptable standard of 10 mg/l was used to establish a phase diagram representing the regional ground water problem (Figure 9). Various policy options in relation to conditions established for the region

were identified.

Consider the policy problem of how to obtain the minimum cost fertilizer use and ground water nitrate concentration level over time. Such a policy strategy for the region may be achieved by following nitrogen fertilizer application rates as indicated by the convergent sepratrice (line B-A and C-A). If the ground water nitrate concentrations were greater than the 13 mg/l (I_0) at steady state then a fertilizer level such as that represented by I_f would allow the steady state to be attained. Thus if the policy objective was to achieve the minimum cost of achieving point of use water quality standards, policies would need to be enforced which followed the convergent sepratrice. Optimal paths above the convergent sepratrice allow for an increase in nitrogen fertilizer availabiltiy, reducing the financial loss to agriculture. Steady state (point A) is the combination of fertilizer and nitrate contamination of ground water which minimizes the cost over time.

Consider another policy option where the objective was not to attain the cost minimizing steady state, but to bring the nitrate concentration level of ground water to a minimum of 10 mg/l. Several paths will lead to a lowering of the nitrates in ground water. Initial nitrate conditions which are to the right of steady state allow for various nitrogen fertilizer applications to be used to achieve ground water quality (Figure 9). Fertilizer application levels which lie

below 7.9 mill lbs., allowed the trajectory paths to intersect the 10 mg/l level. Applications of fertilizer which lie above 7.9 mill lbs. would not allow the steady state or the 10 mg/l concentrations levels to be attained.

Nitrate concentrations which are to the left of steady state also allow achievement of the 10 mg/l nitrate concentration objective. Fertilizer levels which are below 12.7 mill lbs. may be used to obtain paths which would provide 10 mg/l concentrations (Figure 9), depending on the initial nitrate concentrations in the ground water.

The dynamic model developed may be used by policy makers to identify economic optimal trajectory paths to achieve several water quality goals. If the concern is to minimize cost, a steady state solution may be derived in which ground water contamination may exceed the 10 mg/l standard. Concerns focusing on keeping the ground water clean, at less than 10 mg/l concentrations levels, may also be obtained from the modeling system by following various trajectory paths.

CHAPTER VI

SUMMARY AND CONCLUSION

Focus of The Study

Contamination of ground water resources from nonpoint agricultural sources is just beginning to be realized. The increased productivity gains which have resulted from the development and use of fertilizers, pesticides, and other chemicals are being identified as potential contributors to the contamination of ground water.

This study sought to examine the dynamic economic conflict between agricultural producers, who contaminate ground water sources, and consumers, who are demanding clean point of use water. The primary objective of the study was to develop a methodology that would allow dynamic regional economic analysis of obtaining improved point of use ground water quality. Specific objectives were:

1. select an agricultural chemical which poses a threat to ground water contamination;
2. estimate the regional agricultural costs associated with restricting the use of the selected chemical;
3. estimate the economic costs associated with point of use ground water contaminant removal; and
4. determine the least cost method available for obtaining point of use water quality goals from ground water which has been contaminated from nonpoint agricultural sources.

Various agricultural chemicals threaten the quality of ground water. Nitrate, a chemical which enters the soil and ground water environment from field applied nitrogen fertilizer was selected as the case study contaminant.

Negative health effects which occur from nitrates are a result of the easy conversion of nitrates to nitrites in the human body. Birth defects, cancers, nervous system impairments, and methemoglobinemia are potential health effects associated with nitrates.

A major component of the study was to develop a methodology and modeling system capable of providing guidance in selecting the least cost options to obtaining quality point of use ground water. Prevention strategies, which restrict nitrogen fertilizer application, and nitrate removal from the water supply at point of use were the two options explored which would achieve water quality. Although environmental policies have recently been directed toward prevention techniques, the research approach taken for this study was indifference between pollution prevention and end of pipe clean up methods. Minimizing cost over time was the criteria goal in selecting a strategy for obtaining clean point of use ground water.

Three modeling techniques were developed and categorized as dynamic optimal control, prevention, and nitrate removal. The three sections were linked through five modeling components: optimal control, statistical estimation, linear

programming, plant growth and leaching, and a budget generator. The dynamic optimal control model was the main modeling tool, with the remaining four models providing data support.

A three county rural region located in Northwest Tennessee was selected as the study area. The three Tennessee counties were Obion, Weakley and Gibson. Various soil types used to represent the study area included: Adler, Birds, Calloway, Collins, Convent, Falaya, Grenada, Loring, Lexington, Memphis, Providence, and Waverly. Corn, soybeans, wheat, and hay were the crops included in the analysis. Continuous corn, corn-soybean-wheat/soybean double crop, continuous soybeans, continuous wheat and continuous hay production were included as crop rotations. Conventional and conservation tillage practices were the two soil management strategies used in the analysis.

Findings Of The Study

The preventive policy section provided information related to the costs imposed on the agricultural industry as a result of restricting nitrogen fertilizer use. A linear programming model provided net revenues associated with profit maximizing combinations of crop rotation, nitrogen use, and nitrate leaching under different nitrogen fertilizer restrictions scenarios. A plant growth and leaching model

identified yield and nitrate leaching responses to various nitrogen fertilizer restriction levels. The budget generator provided assimilated production cost information for corn , wheat, hay and soybean crops. The nitrate removal section included estimation of clean up costs. A ion exchange nitrate removal system was used to estimate costs associated with nitrate removal.

Adler, Collins, and Loring soils produced the greatest crop yields. Corn yields were largest on the Adler soil. Wheat yields were greatest on the Loring soil while both Collins and Adler soil had high soybean production. Waverly, Memphis, Falaya and Convent soils provided the poorest medium for crop production. Waverly soils allowed the lowest corn production yield while wheat yields were poorest on Falaya and Convent soils.

Nitrate leaching was related to soil type, tillage practice, crop rotation and fertilizer application levels. Soils which had the greatest amount of nitrate leaching included Memphis, Lexington, and Calloway. The most leaching occurred when a continuous soybean crop rotation was utilized.

Crop rotations which included soybeans had smaller reductions in yields as nitrogen fertilizer availability was restricted. Nitrogen provided by the soybeans partially compensated for the reduced field applied nitrogen fertilizer.

Base crop production for the region was established at 17,876,811 bushels, 11,772,886 bushels and 6,579,141 bushels

for corn, soybeans, and wheat production respectively. Restricting nitrogen fertilizer use to 10 percent of the base value, resulted in a five percent decrease in soybean production, a 10 percent decrease in corn production, and a 15 percent decrease in wheat production. Hay production was not produced under any of the alternative nitrogen restrictions scenarios. Memphis soil, with a 12 percent slope, was the only soil type to be removed from production as nitrogen fertilizer was restricted. Corn-soybean-wheat/soybean crop rotation and conventional tillage were dominant under all scenarios. Economic impacts for the region, as a result of restricting nitrogen fertilizer use, were not substantial. Net revenue decreased approximately 9 percent as fertilizer use was restricted to 10 percent of the base line level.

The dynamic optimal control model identified the minimum cost method of achieving point of use water quality over time. A saddle point steady state solution was obtained for the case study. All parameter values in the optimal control model were known, or estimated through use of other models, with the exception of ground water volume.

A sensitivity analysis was conducted for each of the parameter values in the model. Two steady state nitrate contamination levels, associated with different volumes of ground water, were used in the sensitivity analysis. A 8 mg/l nitrate concentration, which was below the 10 mg/l standard, was defined as the no problem scenario. The second steady

state solution was established with nitrate concentration levels at 16 mg/l, above the standard and defined as the problem scenario. Parameter values were adjusted so the steady state nitrate concentration of ground water would decrease from 16 mg/l to 8 mg/l.

The optimal control model was most sensitivity to adjustments in the recharge and leaching parameters. A doubling of the recharge rate, or a reduction in the leaching coefficient by one half, resulted in the nitrate concentration level decreasing to 8 mg/l. Variations in the yearly consumption of water, as well as in the cost of nitrate removal, did not result in substantial changes in the output for the optimal control model. A 70 fold increase in either water consumption or in nitrate removal costs was required to bring the nitrate level from 16 mg/l to 8 mg/l. The optimal control model was not sensitive to changes in the discount rate.

The financial cost imposed on agriculture at the steady state solution of 16 mg/l was \$38,370, the respective nitrate removal costs were \$3,568,000. Over time the balance between fertilizer application, hydrologic characteristics of the regional ground water aquifers and nitrate removal at point of used resulted in the consumers absorbing most of the cost for obtaining clean water. The agricultural industry was only responsible for the cost of clean water when nitrate removal costs substantially increased or the population in the region

was significantly larger than currently existed in the study area.

The dynamic optimal control model allowed the development of solutions which would bring the nitrate contamination level of the aquifer to the acceptable level of 10 mg/l. Depending on the initial nitrate concentrations in the aquifer, various strategies of restricting nitrogen fertilizer application, would result in acceptable levels of nitrate in point of use water.

Limitations

The study attempted to merge dynamic hydrologic characteristics of a regional ground water system, associated with the nitrate contaminant, and the dynamic economics of obtaining point of use water quality. Obtaining complete detailed hydrologic data for the three county study area was not possible. The result was that the hydrologic components, in the optimal control model, were a generalized representation of the ground water system for the region. Detailed data related to water movement and the nitrate chemical interaction with the ground water system were not captured.

Volume of ground water for the aquifers was unknown. Although this did not affect model performance and reliability, numerical solutions which were obtained were

hypothetical.

The plant growth and leaching model selected, EPIC, provided information on relationships between crop yields, nitrate leaching and fertilizer application. Although EPIC was the only simulation model found in the literature which provided such relationships, it was not specifically designed as a leaching simulation model. The leaching information, as a result, may not be as detailed or sensitive to the physical subsurface surroundings as other ground water models may have provided.

Benefits to the financial status of farm operators as a result of U.S. farm commodity programs were not captured. The financial returns to farm operators were therefore underestimated.

Further Research

Analyzing the economics of obtaining ground water quality which has been contaminated from non point agricultural sources was complex and involved various sciences, including hydrology, soil, and economics. The conflict between use of chemicals in agricultural production and maintaining point of use water quality should continue with more in depth modeling and information collection efforts.

Hydrologic characteristics play a significant role in identifying optimal solutions to the agricultural nonpoint

source contamination of ground water. A study which focused and incorporates more detailed and sophisticated hydrological characteristics into the developed modeling system is suggested. This would include more accurate representation of the leaching process and water movement in the aquifer system.

United States farm commodity programs have a significant impact on the financial condition of the agricultural sector. Incorporating agricultural farm programs into the study would more accurately capture the financial response to nitrogen fertilizer restriction scenarios.

LITERATURE CITED



LITERATURE CITED

- Adelman, D. D., W. J. Schroeder, R. J. Smaus, and G. R. Wallin. 1985. "Overview of Nitrate in Nebraska's Groundwater." *Trans., Nebr. Acad. Sci.*, Vol. 13, pp. 75-81.
- Alderfer, Ronald G., and Eldridge Lovelace. 1977. "Relationship Between Water Quality Management Planning and Land Use Planning." In Joseph L. Pavoni [ed.], Handbook of Water Quality Management Planning, Von Nostrand Reinhold Company.
- Agriculture, Resource, and Environmental Policy Research Consortium. 1989. "Water Quality and Agriculture: An International Perspective on Policies." *Proceedings of a Symposium - Presented by the Agricultural, Resource and Environmental Policy Research Consortium* Washington, DC, April.
- Amemiya, Min. 1982. "Why the Concern about Agricultural Nonpoint Pollution." Iowa Agriculture and Water Cooperative Extension Service, Iowa State University, Ames, Iowa.
- Anderson, Glen D., James J. Opaluch, and W. Michael Sullivan. 1985. "Nonpoint Agricultural Pollution: Pesticide Contamination of Ground Water Supplies." American Journal of Agricultural Economics, December.
- Baker, J. L. 1985. "Conservation Tillage: Water Quality Considerations." In F.M. D'Irti [ed.], A Systems Approach to Conservation Tillage, Lewis Publ. Inc., Chelsea, Michigan, pp. 217-238.
- Baker, J. L., and H. P. Johnson. 1983. "Evaluating the Effectiveness of BMPs from Field Studies." In F. Schaller and G. Bailey [eds.], Agricultural Management and Water Quality, Iowa State University Press, Ames, Iowa, pp. 281-304.
- Baker, J. L., and J. M. Laflen. 1983. "Water Quality Consequences of Conservation Tillage." Journal of Soil and Water Conservation, Vol. 38, pp. 186-193.
- Baker, J. L., and H. P. Johnson. 1981. "Nitrate-Nitrogen in Tile Drainage as Affected by Fertilization." Journal of Environmental Quality, Vol. 10, pp. 519-522.

- Batie, Sandra S. 1988. "Agriculture as the Problem-The Case of Ground Water Contamination." Choices.
- Batie, Sandra S. 1986. "Envrionmental Limits: The New Constraints." Issues in Science and Technology, Fall.
- Batie, Sandra S. 1984. "Alternative Views of Property Rights: Implications for Agricultural Use of Natural Resources." American Journal of Agricultural Economics, December.
- Benbrook, Charles M. 1988. "The Environment and the 1990 Farm Bill." Journal of Soil and Water Conservation, pp. 440-444, November-December.
- Blackmer, A. M. 1986. "Potential Yield Response of Corn to Treatments That Conserve Fertilizer Nitrogen in Soils." Agronomic Journal, Vol. 78, No. 4, pp. 571-575.
- Blodgett, J. E., and E. H. Clarke II. 1986. "Fertilizers, Nitrates, and Groundwater: An Overview." In Proc., Colloquium on Agricultural Management and Water Quality, Nat. Res. Council, Nat. Acad. Press, Washington, D.C.
- Bredehoeft, J. D., and G. F. Pinder. 1973. "Mass Transportation In Flowing Ground Water." Water Resource Research, Vol. 9, No. 1, pp. 194-210.
- Broadbent, Francis E., and Roy S. Rauschkolb. 1977. "Nitrogen Fertilizer and Water Pollution." California Agriculture, Volume 31, No. 5, pp. 24-25.
- Buntley, G.J., and Frank F. Bell. 1976. "Yield Estimates for the Major Crops Grown on the Soils of West Tennessee." Bulletin 561, Agricultural Experiment Station, Knoxville, Tennessee.
- Burden, E. H. W. J. 1961. "The Toxicology of Nitrates and Nitrites with Particular Reference to the Potability of Water Supplies." Analyst, Vol. 86, pp. 429-433.
- Busch, Darron, and Michael Meyer. 1982. "A Case of Infantile Methemoglobinemia In South Dakota." Journal of Environmental Health, Vol. 44, No. 6, pp. 310-311.
- Canter, Larry W. Robert C. Knox, and Deborah M. Fairchild. 1987. Groundwater Quality Protection. Lewis Publishers, Inc., Chelsea, Michigan.

- Center for Business and Economic Research. 1989. "Tennessee Statistical Abstracts." University of Tennessee, Knoxville, Tennessee.
- Chichester, F. W. 1977. "Effects of Increased Fertilizer Rates on Nitrogen Content of Runoff and Percolate from Monolith Lysimeters." Journal of Environmental Quality, Vol. 6, No. 2, pp. 211-217.
- Clark, Colin W. 1976. Mathematical Bioeconomics: The Optimal Management of Renewable Resources. John Wiley & Sons, New York.
- Clark, E. H. II, and N. B. Richardson. 1986. "Agriculture Not Sole Culprit." Solutions, J. Fluid Fert./Ag. Chem. Ind., Vol. 30, No. 5, pp. 32-36.
- Clifford, Dennis A., and Walter J. Weber Jr. 1978. "Nitrate Removal from Water Supplies by ION Exchange." Municipal Environmental Research Laboratory Office of Research and Development, United States Environmental Protection Agency, Cincinnati Ohio, Report EPA-600/2-78-052, June.
- Coady, Sean A., Gary V. Cole and Burton C. English. 1990. "Developing Two Representative Farms For Major Land Resource Area 134: The Upper Mississippi Valley Silty Uplands - Weakley, and Hayward Counties, Tennessee." Research Report, Department of Agricultural Economics and Rural Sociology, University of Tennessee, Knoxville.
- Cole, Gary V., and Burton C. English. 1990. "The Micro Oriented Agricultural Production System (MOAPS): A Documentation." Agricultural Experiment Station Research Report #90-03, Department of Agricultural Economics and Rural Sociology, University of Tennessee, Knoxville.
- Council for Agricultural Science and Technology (CAST). 1985. "Agriculture and Groundwater Quality." ISSN; 194-4088; No. 103. Headquarters Office, Iowa State University Station, Ames, Iowa.
- Crowder, Bradley and C. Edwin Young. 1988. "Managing Farm Nutrient Tradeoffs for Surface-and Ground-Water Quality." Agricultural Economic Report Number 583, United States Department of Agriculture, Economic Research Service.

- Crutchfield, Stephen R. 1989. "Agriculture and Water Quality: An Overview and Outlook." Environmental Quality Valuation Section, Resources and Technology Division, Economic Research Service. Prepared for W-178 meeting: "Water Management and Conservation in Western Irrigated Agriculture", Wagoner, Oklahoma, November.
- Devault, G. 1986. "Spend Less, Make More, and Keep EPA off Your Back." The New Farm, Vol. 8, No. 5, pp. 40-41.
- Dorfman, R. 1969. "An Economic Interpretation of Optimal Control Theory." American Economic Review, Vol. 59, pp. 817-831.
- Elfving, J. 1986. "Fingerprinting Pollution at Iowa's Big Spring." Environmental Protection Agency Journal, Vol. 12, No. 4, p. 19.
- Guter, Gerald A. 1982. "Removal of Nitrate from Contaminated Water Supplies for Public use: Final Report." United States Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio, EPA-600/S2-82-042.
- Hallberg, G. R. 1985. "Groundwater Quality and Agricultural Chemicals: A Perspective from Iowa." Proceedings, North Central Weed Control Conference, Vol. 40, pp. 130-147.
- Hallberg, G. R. 1986a. "Agrichemicals and Water Quality." In Proc., Colloquium on Agrichemical Management and Water Quality, National Research Council, National Academy Press, Washington, DC.
- Hallberg, G. R. 1986b. "Overview of Agricultural Chemicals in Groundwater" In Agricultural Impacts on Ground Water, National Water Well Assoc., Worthington, Ohio.
- Hallberg, G. R. 1986c. "Nitrates in Groundwater in Iowa." In Proceedings, Nitrogen and Groundwater Conference, Iowa Fertilizer and Chemical Association, Des Moines, Iowa.
- Hallberg, George R. 1986d. "FROM HOES TO HERBICIDES Agriculture and Groundwater Quality." Journal of Soil and Water Conservation, November-December.
- Hallberg, G. R., R. D. Libra, and B. E. Hoyer. 1985. "Nonpoint Source Contamination of Groundwater in Karst-Carbonate Aquifers in Iowa." In perspectives on Nonpoint Source Pollution, Washington, DC, EPA 440/5 85-001, pp. 109-114.

- Hallberg, G. R., R. D. Libra, E. A. Bettis III, and B. E. Hoyer. 1984. "Hydrogeologic and Water-Quality Investigations in the Big Spring Basin, Clayton County, Iowa: 1983 Water Year." Report 84-4, Iowa Geological Survey, Iowa City, Iowa.
- Harlburt, Scott. 1988. "Problems with Nitrates" Water Well Journal, Vol. 42., No. 8, pp. 37-42.
- Heady, Earl O., and Gary Vocke. 1979. "Programmed Impacts of Environmental Restraints Applied to U.S. Agriculture." Journal of Environmental Quality, Volume 8, No. 2, April-June.
- Hill, A. R. 1982. "Nitrate Distribution in the Ground Water of the Alliston Region of Ontario, Canada." Ground Water, Vol. 20, No. 6, pp. 696-702.
- Hillier, Frederick S., and Gerald J. Lieberman. 1986. Introduction to Operations Research, Holden-Day, Inc. Oakland, California.
- Hinkle, M. K. 1983. "Problems with Conservation Tillage." Journal of Soil and Water Conservation, Vol. 38, pp. 201-206.
- Hoag, Danna. 1987. "Budget Planner User's Guide." Microcomputer Farm Management Series, Agricultural Extension Service, North Carolina State University.
- Horner, Gerald L. 1975. "Internalizing Agricultural Nitrogen Pollution Externalities: A Case Study." American Journal of Agricultural Economics, February.
- Hueth, D., and U. Regev. 1974. "Optimal Agricultural Pest Management with Increasing Pest Resistance." American Journal of Agricultural Economics, August.
- Huffaker, Ray G., James E. Wilen and B. D. Gardner. 1989. "Multiple Use Benefits on Public Rangelands: An Incentive-Based Fee System." American Journal of Agricultural Economics, August.
- Hwang, Jack C., Woncheol C. Cho, and G. T. Yeh. 1984. "An Eigenvalue Solution Continuous in Time to the Spatially Discretized Solute Transport Equation in Steady Ground Water Flow." Water Resources Research, Vol. 20, No. 11. pp. 1725-1732, November.
- Intriligator, Michael D. 1971. Mathematical Optimizations and Economic Theory. Prentice Hall, Inc., Englewood Cliffs, New Jersey.

- Johnson, Gordon V. 1987. "Soil Testing as a Guide to Prudent Use of Nitrogen Fertilizers in Oklahoma Agriculture." In Deborah M. Fairchild [ed.], Ground Water Quality and Agricultural Practices, Lewis Publishers, Chelsea, Michigan.
- Johnson, Larry A. 1989. "Field Crop Budgets for 1990." Department of Agricultural Economics and Rural Development, Agricultural Extension Service, University of Tennessee, Knoxville, Tennessee, December.
- Johnson, L.A. 1987. "Tennessee Budget Generator, Documentation for the Lotus Template." Department of Agricultural Economics and Rural Development, University of Tennessee, Knoxville, Tennessee.
- Jones, C. A., and Kiriya J. R. (editors). 1986. "CERES-MAIZE A Simulation of Maize Growth and Development." Texas A&M University Press.
- Keeney, D. R. 1986a. "Nitrate in Ground Water-Agricultural Contribution and Control." In Agricultural Impacts on Groundwater, National Water Well Association, Worthington, Ohio.
- Keeney, D. R. 1986b. "Sources of Nitrate to Ground Water." In Critical Reviews in Environmental Control, CRC Vol. 16, No. 3, pp. 257-304.
- Kernodel, John Michael and John M. Wilson. 1973. "Water Use in Tennessee." Water use Source Number 6, Tennessee Department of Conservation, Division of Water Resources, Nashville, Tennessee.
- Kerr, Robert S. 1985. "DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings." Environmental Research Laboratory, Ada, Oklahoma, EPA/600/2-85/018.
- Kerr, Robert S. 1979. "Identifying Sources of Subsurface Nitrate Pollution with Stable Nitrogen Isotopes." United States Environmental Protection Agency, Environmental Research Laboratory, EPA-600/4-79-050, August.
- Kerr, Robert S. 1977. "The Control of Nitrate as a Water Pollutant." Office of Research and Development, United States Environmental Protection Agency, Ada Oklahoma, EPA-600/2-77-158, August.

- Kim, C. S., and Michael R. Moore. 1988. "Public Policies in Water-Resource Use: A Theoretical Analysis of Their Effect on Groundwater Mining and Surface Water Importation." Paper Presented at the Annual Western Agricultural Economic Association Meetings, Honolulu, Hawaii, July 10-13.
- Kletke, Darrel D. 1979. "Operation of the Enterprise Budget Generator." Agricultural Experiment Station Research Report P-790, Department of Agricultural Economics, Oklahoma State University, Stillwater, Oklahoma.
- Klinko, Deborah K., and Charles W. Abdalla. 1989. "Cooperative Versus Individual Approaches to Treatment of Contaminated Groundwater by Rural Residents in the Northeast." Northeastern Journal of Agricultural and Resource Economics, Vol. 18, No. 1.
- Lee, Douglas H. K. 1970. "Nitrates, Nitrites, and Methemoglobinemia." Environmental Research, Vol. 3, pp. 484-511.
- McGrann, James M., Kent D. Olson, Timothy A. Powell, Ted R. Nelson, and clay Laird. 1986. "Microcomputer Budget Management System User Manual." Department of Agricultural Economics, Texas A&M University, College Station, Texas, September.
- Mundy, Darrel S., and Morgan D. Gray. 1986. "Types of Farming in Tennessee." Agricultural Experiment Station Bulletin 646, University of Tennessee, Knoxville, Tennessee.
- National Research Council. 1978. "Nitrates: An Environmental Assessment." A Report Prepared by the Panel on Nitrates of the Coordinating Committee for Scientific and Technical Assessments of Environmental Pollutants, National Academy of Sciences, Washington, DC.
- Nielsen, Elizabeth G., and Linda K. Lee. 1987. "The Magnitude and Costs of Groundwater Contamination from Agricultural Chemicals: A National Perspective." Agricultural Economic Report Number 576, United States Department of Agriculture, Economic Research Service, Natural Resource Economic Division, October.
- Novotny, Vladimir, and Gordon Chester. 1981. Handbook of Nonpoint Pollution Sources and Management, Van Nostrand Reinhold Company.

- Olson, R. A. 1985. "Nitrogen Problems." In Plant Nutrient Use and the Environment, The Fertilizer Inst., Washington, DC, pp. 115-138.
- Olson, R. A., K. D. Frank, P. H. Grabouski, and G. W. Rehm. 1982. "Economic and Agronomic Impacts of Varied Philosophies of Soil Testing." Agronomic Journal, Vol. 74, pp. 492-499.
- Olsen, R. J., R. F. Hensler, O. J. Attoe, S. A. Witzel, and L. A. Peterson. 1970. "Fertilizer Nitrogen and Crop Rotation in Relation to Movement of Nitrate Nitrogen Through Soil Profiles. Soil Sci. Soc. Am. Proc, Vol 34, pp. 448-452.
- Organisation for Economic Co-operation and Development. 1986. Water Pollution by Fertilizers and Pesticides. Published by the Organisation for Economic Co-operation and Development.
- Office of Technology Assessment. 1984. "Protecting the Nation's Ground Water from Contamination." OTA-0-276, Volume II, United States Government Printing Office, Washington, DC.
- Plant, Richard E., Marc Mangel and Lawrence E. Flynn. 1985. "Multiseasonal Management of an Agricultural Pest II: The Economic Optimization Problem." Journal of Environmental Economics and Management, Vol. 12, pp. 45-61.
- Pojasek, Robert B. 1977. Drinking Water Quality Enhancement Through Source Protection. Ann Arbor Science Publishers Inc., Ann Arbor Michigan.
- Putman, John W., and Paul T. Dyke. 1987. "The Erosion Productivity Impact Calculatory as Formulated for the Resource Conservation Act Appraisal." United States Department of Agriculture, Economic Research Service, Natural Resource Economic Division, June.
- Pye, Veronica I., Ruth Patrick, and John Quarles. 1983. Groundwater Contamination in the United States. University of Pennsylvania Press, Philadelphia.
- Richardson, J.W. and C.J. Nixon. 1986. "Description of FLIPSIM V; A General Firm Level Policy Simulation Model." Agricultural and Food Policy Center, Department of Agricultural Economics, Texas A&M University, College Station, Texas.

- Schechter, Mordechai. 1985. "An Anatomy of a Groundwater Contamination Episode." Journal of Environmental Economics and Management, Vol. 12, pp. 72-88.
- Sharefkin, Mark, Mordechai Shechter and Allen Kneese. 1984. "Impacts, Costs, and Techniques for Mitigation of Contaminated Groundwater: A Review." Water Resources Research, Vol 20, No. 12, pp. 1771-1783, December.
- Singh, Bijay, and G. S. Sekhon. 1978/79. "Nitrate Pollution of Ground Water from Farm use of Nitrogen Fertilizers - A Review." Agriculture and Environment, Vol. 34, pp. 207-225.
- Spence, Michael, and David Starrett. 1975. "Most Rapid Approach Paths in Accumulation Problems." International Economic Review, Vol. 16, No. 2, June.
- SRA Technologies, Inc. 1986. "Agricultural Chemicals in Groundwater: Problem Statement." Prepared for the Office of Pesticide and Toxic Substances, United States Environmental Protection Agency, Draft Report, May 13.
- Stewart, Bobby A. 1987. "The U.S.D.A. Agricultural Research Service Commitment to Ground Water Research." in Deborah M. Fairchild [ed.], Ground Water Quality and Agricultural Practices, Lewis Publ. Inc., Chelsea, Michigan, pp. 1-5.
- Raucher, Robert L. 1983. "A Conceptual Framework for Measuring the Benefits of Groundwater Protection." Water Resources Research, Vol. 19, No. 2, pg. 320-326. April.
- Soil Conservation Society of America. 1979. "Effects of Tillage and Crop Residue Removal on Erosion, Runoff, and Plant Nutrients." A series of articles from the Journal of Soil and Water Conservation, Special Publication No. 25, Ankeny, Iowa.
- Swoboda, Allen R. 1977. "The Control of Nitrate as a Water Pollutant." Office of Research and Development, United States Environmental Protection Agency, Ada Oklahoma. Report EPA-600/2-77-158, August.
- Taylor, Robert C., and Klaus K. Frohberg. 1977. "The Welfare Effects of Erosion Controls, Banning Pesticides, and Limiting Fertilizer Application in the Corn Belt." American Journal of Agricultural Economics, February.

- Tennessee Department of Agriculture. 1989. "Tennessee Agriculture" Ellington Agriculture Center, Nashville, Tennessee.
- Tennessee Department of Health and Environment. 1986. "The Status of Water Quality in Tennessee." Office of Water Management, Report 305(b), August.
- Tennessee Ground Water Policy Dialogue Group. 1987. "Recommendations to the Commissioner of Health and Environment", The Governor's Safe Growth Cabinet Council and the Water Quality Control Board."
- United States Department of Agriculture. 1989. "A National Program for Soil and Water Conservation: The 1988-97 Update." January.
- United States Department of Agriculture. 1981. "Land Resource Regions and Major Land Resource Areas of the United States." Soil conservation Service, Agriculture Handbook 296, December.
- United States Department of Agriculture. 1982. "National Resource Inventory." Soil Conservation Service.
- United States Department of Agriculture. 1973a. "Soil Survey, Gibson County Tennessee." Soil Conservation Service, in cooperation with the Tennessee Agricultural Experiment Station.
- United States Department of Agriculture. 1973b. "Soil Survey, Obion County Tennessee." Soil Conservation Service, in cooperation with the Tennessee Agricultural Experiment Station.
- United States Department of Agriculture. 1973c. "Soil Survey, Weakley County Tennessee." Soil Conservation Service, in cooperation with the Tennessee Agricultural Experiment Station.
- United States Department of Agriculture. 1970. "Fertilizer Use and Water Quality." Agricultural Research Service, ARS, 41-168.
- United States Department of the Interior. 1988. "Reelfoot Lake Water Level Management Draft Environmental Impact Statement." Fish and Wildlife Service, Southeast Region, Atlanta, Georgia.
- United States Department of Labor. 1990. "CPI Detailed Report." Bureau of Labor Statistics, April.

- United States Environmental Protection Agency. 1983.
"Nitrate Removal for Small Public Water Systems."
Prepared by SMC Martin, Valley Forge PA for the Office
of Drinking Water, USEPA Report 570/9-83-009, June.
- United States Environmental Protection Agency. 1979.
"Effectiveness of Soil and Water Conservation Practices
for Pollution Control." Douglas A. Haith and Raymond C.
Loehr [ed.], College of Agriculture and Life Sciences,
Cornell University. Project Officer Lee A. Mulkey,
Technology Development and Application Branch,
Environmental Research Laboratory, Athens, Georgia,
Report EPA-600/3-79-106.
- United States Soil Conservation Service. 1979. "Soil Survey
Laboratory Data and Descriptions for Some Soils of
Louisiana." Soil Survey Investigation Report Number 35.
- United States Soil Conservation Service. 1967a. "Soil Survey
Laboratory Data and Descriptions for Some Soils of
Georgia, North Carolina, South Carolina, and
Tennessee." Soil Survey Investigations Report Number
16.
- United States Soil Conservation Service. 1967b. "Soil Survey
Laboratory Data and Descriptions for Some Soils of
Mississippi and Kentucky." Soil Survey Investigations
Report Numbers 13 and 14.
- United States Soil Conservation Service. 1966. "Soil Survey
Laboratory Data and Descriptions for Some Soils of
arkansas, Louisiana, and Missouri." Soil Survey
Investigation Report Number 6.
- Upton, Charles. 1968. "Optimal Taxing of Water Pollution."
Water Resource Research, Vol. 4, No. 5, October.
- Viets, Frank G., Jr. 1965. "The Plant's Need for and Use of
Nitrogen." In W. V. Bartholomew and F. E. Clark [eds.],
Soil Nitrogen Agronomy, Vol. 10, American Society of
Agronomy, Inc., Madison, Wisconsin, pp. 503-549.
- Wilkerson G. G., J. W. Jones, K, J, Boote and J. W. Mishoe.
1985. "SOYGROW V5.0: Soybean Crop Growth and Yield
Model Technical Documentation." Agricultural
Engineering Department and Agronomy Department,
University of Florida, Gainesville, Florida.
- Walton, G. 1951. American Journal of Public Health, Vol. 41,
p. 986.

- Williams, J.R., P.T. Dyke, and C.A. Jones. 1982. "EPIC -- A Model for Assessing the Effects of Erosion on Soil Productivity." Paper presented at the Third International Conference on State-of-the Art in Ecological Modelling, Colorado State University, May 24-28.
- Willis, Robert. 1979. "A Planning Model for the Mangement of Groundwater Quality." Water Resources Research, Vol. 15, No. 6, December.
- Wilson, J. L., and P. J. Miller. 1978. "Two Dimensional Plume in Uniform Groundwater Flow." Journal of Hydraulics, American Society of Engineers, Vol. 46, pp. 165-181.
- Wolff, I. A. and A. E. Wasserman. 1972. "Nitrates, Nitrites, and Nitrosamines." Science, Vol. 177, No. 4043, p. 15.
- Worthington, Virginia E., Oscar R. Burt, and Richard L. Brustkern. 1985. "Optimal Management of a Confined Groundwater System." Journal of Environmental Economics and Management, Vol. 12, pp. 229-245.
- World Health Organization. 1984. Guidelines for Drinking-Water Quality. Volume 2, Macmillan/Ceuterick Publishers.
- World Health Organization. 1978. Nitrates, Nitrites and N-nitroso Compounds. (Environmental Health Criteria 5), Macmillan/Ceuterick Publishers.
- Wright, C. 1974. "Some Political Aspects of Pollution Control." Journal of Environmental Economics and Management, Vol. 1, pp. 553-546.
- Zurawski, Ann. 1978. "Summary Appraisals of the Nations's Ground-Water Resources - Tennessee Region." Geological Survey Professional Paper 813-L, United States Government Printing Office, Washington, DC.

APPENDICES

APPENDIX A
PRODUCTION COSTS

Appendix Table A-1. Production Costs for a Continuous Corn Crop Rotation Under Conventional Tillage.

Cost Item	Corn
	\$ per acre
Variable Cost	
Seed	16.15
Fertilizer	54.25
Chemicals	14.94
Fuel-Lube	15.48
Repairs	23.38
Labor	6.93
Sub Total	131.13
Fixed Cost for the Rotation	
Cash Rent ^a	13.09
Property Tax	2.07
Interest Long	
Term Debt	4.09
Interest	
Interm. Debt	3.72
Interest	
Operating Debt	4.29
Principle Long	
Term Debt	5.49
Principle	
Interm. Debt	6.06
Other Fixed	11.29
Sub Total	50.10
Total Rotation Cost	
Variable plus Fixed	<u>\$181.23</u>

^a Cash rent expenses were distributed equally among total farm acres (owned and rented).

Appendix Table A-2. Production Costs for a Continuous Corn Crop Rotation Under Conservation Tillage.

Cost Item	Corn
	\$ per acre
Variable Cost	
Seed	16.15
Fertilizer	54.25
Chemicals	38.24
Fuel-Lube	7.45
Repairs	17.12
Labor	4.05
Sub Total	137.26
Fixed Cost for the Rotation	
Cash Rent ^a	13.09
Property Tax	2.07
Interest Long Term Debt	4.09
Interest Interm. Debt	3.79
Interest Operating Debt	4.83
Principle Long Term Debt	5.49
Principle Interm. Debt	6.14
Other Fixed	11.29
Sub Total	50.79
Total Rotation Cost Variable plus Fixed	<u>\$188.05</u>

^a Cash rent expenses were distributed equally among total farm acres (owned and rented).

Appendix Table A-3. Production Costs for a Corn - Soybean Crop Rotation, Under Conventional Tillage.

Cost Item	Corn	Soybeans
	\$ per acre.....	
Variable Cost		
Seed	16.15	7.29
Fertilizer	54.25	23.78
Chemicals	14.94	12.85
Fuel-Lube	15.48	10.97
Repairs	9.46	15.25
Labor		
Sub Total	117.21	75.81
Fixed Cost for the Rotation		
Cash Rent ^a	13.09	13.09
Property Tax	2.07	2.07
Interest Long Term Debt	4.09	4.09
Interest Interm. Debt	3.84	3.84
Interest Operating Debt	3.98	3.98
Principle Long Term Debt	5.49	5.49
Principle Interm. Debt	6.22	6.22
Other Fixed	11.29	11.29
Sub Total	50.07	50.07
Total Rotation Cost		
Variable plus Fixed	<u>293.16</u>	

^a Cash rent expenses were distributed equally among total farm acres (owned and rented).

Appendix Table A-4. Production Costs for Corn - Soybean Crop Rotation, Conservation Tillage.

Cost Item	Corn	Soybeans
	\$ per acre.....	
Variable Cost		
Seed	16.15	7.29
Fertilizer	54.25	23.78
Chemicals	38.24	30.59
Fuel-Lube	7.29	6.33
Repairs	16.77	13.98
Labor	4.50	3.69
Sub Total	137.20	85.66
Fixed Cost for the Rotation		
Cash Rent ^a	13.09	13.09
Property Tax	2.07	2.07
Interest Long Term Debt	4.09	4.09
Interest Interm. Debt	3.88	3.88
Interest Operating Debt	4.73	4.73
Principle Long Term Debt	5.49	5.49
Principle Interm. Debt	6.32	6.32
Other Fixed	11.29	11.29
Sub Total	50.96	50.96
Total Rotation Cost Variable plus Fixed	<u>324.78</u>	

^a Cash rent expenses were distributed equally among total farm acres (owned and rented).

Appendix Table A-5. Production Costs for a Corn - Soybean - Wheat/Soybean Crop Rotation Under Conventional Tillage.

Cost Item	Corn	Soybeans	Wheat/Soybeans
	\$ per acre.....		
Variable Cost			
Seed	16.15	7.29	19.29
Fertilizer	54.25	23.78	41.64
Chemicals	14.94	12.85	22.99
Fuel-Lube	15.47	10.97	10.37
Repairs	23.38	15.25	22.69
Labor	6.93	5.67	7.34
Sub Total	131.13	75.81	124.32
Fixed Cost for the Rotation			
Cash Rent ^a	13.09	13.09	13.09
Property Tax	2.07	2.07	2.07
Interest Long Term Debt	4.09	4.09	4.09
Interest Interm. Debt	4.57	4.57	4.57
Interest Operating Debt	4.21	4.21	4.21
Principle Long Term Debt	5.49	5.49	5.49
Principle Interm. Debt	7.43	7.43	7.43
Other Fixed	11.29	11.29	11.29
SubTotal	52.24	52.24	52.24
Total Rotation Cost Variable plus Fixed	<u>487.98</u>		

^a Cash rent expenses were distributed equally among total farm acres (owned and rented).

Appendix Table A-6. Production Costs for a Corn - Soybean - Wheat/Soybean Crop Rotation Under Conservation Tillage.

Cost Item	Corn	Soybeans	Wheat/Soybeans
	\$ per acre.....		
Variable Cost			
Seed	16.15	7.29	19.29
Fertilizer	54.25	23.78	41.64
Chemicals	38.24	30.59	22.99
Fuel-Lube	7.28	6.32	10.57
Repairs	16.61	13.82	22.89
Labor	4.18	3.38	7.47
Sub Total	136.71	85.18	124.85
Fixed Cost for the Rotation			
Cash Rent ^a	13.09	13.09	13.09
Property Tax	2.07	2.07	2.07
Interest Long Term Debt	4.09	4.09	4.09
Interest Interm. Debt	4.20	4.20	4.20
Interest Operating Debt	4.82	4.82	4.82
Principle Long Term Debt	5.49	5.49	5.49
Principle Interm. Debt	6.81	6.81	6.81
Other Fixed	11.29	11.29	11.29
Sub Total	51.86	51.86	51.86
Total Rotation Cost Variable plus Fixed	<u>502.32</u>		

^a Cash rent expenses were distributed equally among total farm acres (owned and rented).

Appendix Table A-7. Production Costs for a Continuous Soybean Crop Rotation Under Conventional Tillage.

Cost Item	Soybeans
	\$ per acre
Variable Cost	
Seed	7.29
Fertilizer	23.78
Chemicals	12.85
Fuel-Lube	10.97
Repairs	15.25
Labor	5.67
Sub Total	75.81
Fixed Cost for the Rotation	
Cash Rent ^a	13.09
Property Tax	2.07
Interest Long Term Debt	4.09
Interest Interm. Debt	3.75
Interest Operating Debt	3.66
Principle Long Term Debt	5.49
Principle Interm. Debt	6.09
Other Fixed	11.29
Sub Total	49.53
Total Rotation Cost	
Variable plus Fixed	<u>\$125.34</u>

^a Cash rent expenses were distributed equally among total farm acres (owned and rented).

Appendix Table A-8. Production Costs for a Continuous Soybean Crop Rotation Under Conservation Tillage.

Cost Item	Soybeans
	\$ per acre
Variable Cost	
Seed	7.29
Fertilizer	23.78
Chemicals	30.59
Fuel-Lube	6.49
Repairs	14.33
Labor	3.24
Sub Total	85.72
Fixed Cost for the Rotation	
Cash Rent ^a	13.09
Property Tax	2.07
Interest Long Term Debt	4.09
Interest Interm. Debt	3.81
Interest Operating Debt	4.62
Principle Long Term Debt	5.49
Principle Interm. Debt	6.17
Other Fixed	11.29
Sub Total	50.63
Total Rotation Cost	
Variable plus Fixed	<u>\$136.65</u>

^a Cash rent expenses were distributed equally among total farm acres (owned and rented).

Appendix Table A-9. Production Costs for a Continuous Wheat Crop Rotation Under Conservation Tillage.

Cost Item	Wheat
	\$ per acre
Variable Cost	
Seed	12.00
Fertilizer	24.60
Chemicals	7.94
Fuel-Lube	8.29
Repairs	11.57
Labor	6.75
Sub Total	71.15
Fixed Cost for the Rotation	
Cash Rent ^a	13.09
Property Tax	2.07
Interest Long	
Term Debt	4.09
Interest	
Interm. Debt	3.50
Interest	
Operating Debt	2.47
Principle Long	
Term Debt	5.49
Principle	
Interm. Debt	5.69
Other Fixed	11.29
Sub Total	47.69
Total Rotation Cost	
Variable plus Fixed	<u>\$118.94</u>

^a Cash rent expenses were distributed equally among total farm acres (owned and rented).

Appendix Table A-10. Production Costs for a Continuous Wheat Crop Rotation Under Conservation Tillage.

Cost Item	Wheat
	\$ per acre
Variable Cost	
Seed	12.00
Fertilizer	24.60
Chemicals	28.20
Fuel-Lube	6.04
Repairs	7.84
Labor	4.45
Sub Total	83.13
Fixed Cost for the Rotation	
Cash Rent ^a	13.09
Property Tax	2.07
Interest Long Term Debt	4.09
Interest Interm. Debt	3.50
Interest Operating Debt	3.33
Principle Long Term Debt	5.49
Principle Interm. Debt	5.69
Other Fixed	11.29
Sub Total	48.55
Total Rotation Cost Variable plus Fixed	<u>\$131.68</u>

^a Cash rent expenses were distributed equally among total farm acres (owned and rented).

Appendix Table A-11. Production Costs for a Hay Rotation Under Conventional Tillage.

Cost Item	Establishment	Yearly hay
	\$ per acre.....	
Variable Cost		
Seed	8.00	0.00
Fertilizer		24.60
Chemicals		0.00
Fuel-Lube	2.48	20.91
Repairs	4.46	38.82
Labor	2.66	21.46
Sub Total	17.60/10 ^a	105.79
Fixed Cost for the Rotation		
Cash Rent ^b		13.09
Property Tax		2.07
Interest Long Term Debt		4.09
Interest Interm. Debt		3.27
Interest Operating Debt		5.89
Principle Long Term Debt		5.49
Principle Interm. Debt		5.31
Other Fixed		11.29
Sub Total		50.50
Total Rotation Cost		
Variable plus Fixed	<u>158.05</u>	

^a Establishment costs were prorated over ten year rotation period

^b Cash rent expenses were distributed equally among total farm acres (owned and rented).

APPENDIX B

EPIC SOIL DATA ASSEMBLY FORMS

*** FORM 6 ***

EPIC DATA ASSEMBLY FORM

ADLER SOIL

7.1 Soil Data

Enter soil access number or name to load from file and skip to Section 10.1 or enter zero and input below.

7.1.1	Soil albedo				0.17
7.1.2	Maximum Number of Soil Layers	[1]			5.00
7.1.3	Minimum Thickness of Maximum Layer (m)	[1]			0.10
7.1.4	Minimum Soil Profile Thickness (m)	[1]			0.10
7.1.5	Initial Soil Water Content Fraction of Field Cap.	[1]			0.00
7.1.6	Minimum Depth to Water Table (m)	[1]			0.75
7.1.7	Maximum Depth to Water Table (m)	[1]			3.00
7.1.8	Initial Depth to Water Table (m)	[1]			0.75
7.1.9	Soil Weather Code	[1]			0.00
7.2.1	Depth from the surface to the bottom of the soil layer				
	.01 .15 .76 1.37 2.0				
7.2.2	Bulk density of the soil layer				
	1.4 1.4 1.4 1.4 1.4				
7.2.3	Wilting point	[1]			
	0 0 0 0 0				
7.2.4	Field capacity	[1]			
	0 0 0 0 0				
7.2.5	Sand content (%)				
	.3 .3 .8 .1 .5				
7.2.6	Silt content (%)				
	92 92 92.2 90.1 75.6				
7.2.7	Organic N concentration	[1]			
	690 690 240 330 510				
7.2.8	Soil pH				
	5.4 5.4 6.7 7.2 6.0				

[1] May be left blank or zero if unknown.

*** FORM 7 ***

EPIC DATA ASSEMBLY FORM

ADLER SOIL

7.3.1	Sum of bases					[1]
	9.1	9.1	8.1	11.4	18.9	
7.3.2	Organic carbon					
	.62	.62	.14	.23	.32	
7.3.3	Calcium carbonate					
	0	0	0	0	0	
7.3.4	Cation exchange capacity					[1]
	0	0	0	0	0	
7.3.5	Coarse fragment content					[1]
	0	0	0	0	0	
7.3.6	Nitrate concentration					[1]
	0	0	0	0	0	
7.3.7	Labile P concentration					[1]
	0	0	0	0	0	
7.3.8	Crop residue (%)					[1]
	0	0	0	0	0	
7.4.1	Bulk density (oven dry)					[1]
	1.4	1.4	1.4	1.4	1.4	
7.4.2	Phosphorus sorption ratio					[1]
	0	0	0	0	0	
7.4.3	Saturated conductivity					[1]
	0	0	0	0	0	
7.4.4	Subsurface flow travel time					[1]
	0	0	0	0	0	
7.4.5	Organic P concentration					[1]
	0	0	0	0	0	

[1] May be left blank or zero if unknown.

***** FORM 6 *****
EPIC DATA ASSEMBLY FORM
BIRDS SOIL

7.1 Soil Data

Enter soil access number or name to load from file and skip to Section 10.1 or enter zero and input below.

7.1.1	Soil albedo									0.17	
7.1.2	Maximum Number of Soil Layers							[1]		10.00	
7.1.3	Minimum Thickness of Maximum Layer (m)							[1]		0.10	
7.1.4	Minimum Soil Profile Thickness (m)							[1]		0.10	
7.1.5	Initial Soil Water Content Fraction of Field Cap.							[1]		0.00	
7.1.6	Minimum Depth to Water Table (m)							[1]		0.10	
7.1.7	Maximum Depth to Water Table (m)							[1]		3.00	
7.1.8	Initial Depth to Water Table (m)							[1]		0.10	
7.1.9	Soil Weather Code							[1]		0.00	
7.2.1	Depth from the surface to the bottom of the soil layer										
		.01	.15	.18	.48	.69	.91	1.17	1.52	1.93	2.00
7.2.2	Bulk density of the soil layer										
		1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.65	1.65	1.65
7.2.3	Wilting point									[1]	
		.138	.138	.138	.152	.171	.171	.171	.119	.109	.175
7.2.4	Field capacity									[1]	
		.273	.273	.273	.273	.294	.294	.304	.337	.340	.340
7.2.5	Sand content (%)										
		1.9	1.9	1.9	1.9	1.0	1.0	1.0	5.5	7.3	2.5
7.2.6	Silt content (%)										
		90.8	90.8	90.8	88.3	87.6	87.6	87.1	77.4	73.9	76.1
7.2.7	Organic N concentration									[1]	
		520	520	520	270	410	410	380	280	130	120
7.2.8	Soil pH										
		4.9	4.9	4.9	5.0	5.0	5.0	4.8	4.8	4.7	5.1

[1] May be left blank or zero if unknown

*** FORM 7 ***

EPIC DATA ASSEMBLY FORM

BIRDS SOIL

7.3.1	Sum of bases								[1]	
	3.4	3.4	3.4	4.0	3.2	3.2	2.8	2.9	4.2	12.2
7.3.2	Organic carbon									
	.54	.54	.54	.26	.44	.44	.40	.15	.13	.12
7.3.3	Calcium carbonate									
	0	0	0	0	0	0	0	0	0	0
7.3.4	Cation exchange capacity								[1]	
	5.3	5.3	5.3	6.2	6.3	6.3	6.1	7.9	9.2	14.5
7.3.5	Coarse fragment content								[1]	
	0	0	0	0	0	0	0	0	0	0
7.3.6	Nitrate concentration								[1]	
	2	2	1	1	1	1	1	1	1	1
7.3.7	Labile P concentration								[1]	
	30	30	10	10	10	10	10	10	10	10
7.3.8	Crop residue (%)								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.1	Bulk density (oven dry)								[1]	
	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.65	1.65	1.65
7.4.2	Phosphorus sorption ratio								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.3	Saturated conductivity								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.4	Subsurface flow travel time								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.5	Organic P concentration								[1]	
	0	0	0	0	0	0	0	0	0	0

[1] May be left blank or zero if unknown

*** FORM 6 ***

EPIC DATA ASSEMBLY FORM

CALLOWAY SOIL

7.1 Soil Data

Enter soil access number or name to load from file and skip to Section 10.1 or enter zero and input below.

7.1.1	Soil albedo									0.14
7.1.2	Maximum Number or Soil Layers							[1]		10.00
7.1.3	Minimum Thickness of Maximum Layer (m)							[1]		0.10
7.1.4	Minimum Soil Profile Thickness (m)							[1]		0.10
7.1.5	Initial Soil Water Content Fraction of Field Cap.							[1]		0.00
7.1.6	Minimum Depth to Water Table (m)							[1]		0.50
7.1.7	Maximum Depth to Water Table (m)							[1]		10.00
7.1.8	Initial Depth to Water Table (m)							[1]		0.50
7.1.9	Soil Weather Code							[1]		0.00
7.2.1	Depth from the surface to the bottom of the soil layer									
	0.01	.15	.18	.28	.39	.51	.76	.94	1.19	1.59
7.2.2	Bulk density of the soil layer									
	1.42	1.42	1.42	1.35	1.40	1.40	1.55	1.60	1.60	1.60
7.2.3	Wilting point								[1]	
	.139	.139	.139	.199	.200	.200	.152	.185	.193	.191
7.2.4	Field capacity								[1]	
	.273	.273	.273	.360	.360	.360	.247	.268	.270	.266
7.2.5	Sand content (%)									
	1.6	1.6	1.6	2.0	2.5	2.5	4.5	2.9	1.9	1.1
7.2.6	Silt content (%)									
	91.1	91.1	91.1	77.6	75.7	75.7	79.0	76.1	73.2	78.9
7.2.7	Organic N concentration								[1]	
	910	910	910	540	460	460	340	80	80	70
7.2.8	Soil pH									
	5.7	5.7	5.7	5.3	5.2	5.2	5.3	5.2	5.1	5.1

[1] May be left blank or zero if unknown.

*** FORM 7 ***

EPIC DATA ASSEMBLY FORM

CALLOWAY SOIL

7.3.1	Sum of bases									[1]
		4.5	4.5	4.5	4.7	5.4	5.4	4.2	6.5	8.0 6.6
7.3.2	Organic carbon									
		1.0	1.0	1.0	.34	.26	.26	.13	.08	.08 .07
7.3.3	Calcium carbonate									
		0	0	0	0	0	0	0	0	0
7.3.4	Cation exchange capacity									[1]
		6.1	6.1	6.1	8.5	96.8	9.8	8.7	12.6	16.0 12.9
7.3.5	Coarse fragment content									[1]
		0	0	0	0	0	0	0	0	0
7.3.6	Nitrate concentration									[1]
		2	2	1	1	1	1	1	1	1
7.3.7	Labile P concentration									[1]
		30	30	10	10	10	10	10	10	10
7.3.8	Crop residue (%)									[1]
		0	0	0	0	0	0	0	0	0
7.4.1	Bulk density (oven dry)									[1]
		1.42	1.42	1.42	1.35	1.40	1.40	1.55	1.60	1.60 1.60
17.4.2	Phosphorus sorption ratio									[1]
		0	0	0	0	0	0	0	0	0
7.4.3	Saturated conductivity									[1]
		0	0	0	0	0	0	0	0	0
7.4.4	Subsurface flow travel time									[1]
		0	0	0	0	0	0	0	0	0
7.4.5	Organic P concentration									[1]
		0	0	0	0	0	0	0	0	0

[1] May be left blank or zero if unknown.

*** FORM 6 ***

EPIC DATA ASSEMBLY FORM

COLLINS SOIL

7.1 Soil Data

Enter soil access number or name to load from file and skip to Section 10.1 or enter zero and input below.

7.1.1	Soil albedo									0.17
7.1.2	Maximum Number of Soil Layers						[1]			10.00
7.1.3	Minimum Thickness of Maximum Layer (m)						[1]			0.10
7.1.4	Minimum Soil Profile Thickness (m)						[1]			0.10
7.1.5	Initial Soil Water Content Fraction of Field Cap.						[1]			0.00
7.1.6	Minimum Depth to Water Table (m)						[1]			0.75
7.1.7	Maximum Depth to Water Table (m)						[1]			3.00
7.1.8	Initial Depth to Water Table (m)						[1]			0.75
7.1.9	Soil Weather Code						[1]			0.00
7.2.1	Depth from the surface to the bottom of the soil layer									
	.01	.15	.18	.48	.69	.91	1.17	1.52	1.93	2.00
7.2.2	Bulk density of the soil layer									
	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.65	1.65	1.65
7.2.3	Wilting point								[1]	
	.138	.138	.138	.152	.171	.171	.171	.119	.109	.175
7.2.4	Field capacity								[1]	
	.273	.273	.273	.273	.294	.294	.304	.337	.340	.340
7.2.5	Sand content (%)									
	1.9	1.9	1.9	1.9	1.0	1.0	1.1	5.5	7.3	2.5
7.2.6	Silt content (%)									
	90.8	90.8	90.8	88.3	87.6	87.6	87.1	77.4	73.9	76.1
7.2.7	Organic N concentration								[1]	
	520	520	520	270	410	410	380	280	130	120
7.2.8	Soil pH									
	4.9	4.9	4.9	5.0	5.0	5.0	4.8	4.8	4.7	5.1

[1] May be left blank or zero if unknown.

*** FORM 7 ***

EPIC DATA ASSEMBLY FORM

COLLINS SOIL

7.3.1	Sum of bases								[1]	
	3.4	3.4	3.4	4.0	3.2	3.2	2.8	2.9	4.2	12.2
7.3.2	Organic carbon									
	.54	.54	.54	.26	.44	.44	.40	.15	.13	.12
7.3.3	Calcium carbonate									
	0	0	0	0	0	0	0	0	0	0
7.3.4	Cation exchange capacity								[1]	
	5.3	5.3	5.3	6.2	6.3	6.3	6.1	7.9	9.2	14.5
7.3.5	Coarse fragment content								[1]	
	0	0	0	0	0	0	0	0	0	0
7.3.6	Nitrate concentration								[1]	
	2	2	1	1	1	1	1	1	1	1
7.3.7	Labile P concentration								[1]	
	30	30	10	10	10	10	10	10	10	10
7.3.8	Crop residue (%)								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.1	Bulk density (oven dry)								[1]	
	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.65	1.65	1.65
7.4.2	Phosphorus sorption ratio								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.3	Saturated conductivity								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.4	Subsurface flow travel time								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.5	Organic P concentration								[1]	
	0	0	0	0	0	0	0	0	0	0

[1] May be left blank or zero if unknown.

*** FORM 6 ***

EPIC DATA ASSEMBLY FORM

CONVENT SOIL

7.1 Soil Data

Enter soil access number or name to load from file and skip to Section 10.1 or enter zero and input below.

7.1.1	Soil albedo									0.17
7.1.2	Maximum Number or Soil Layers						[1]			10.00
7.1.3	Minimum Thickness of Maximum Layer (m)						[1]			0.10
7.1.4	Minimum Soil Profile Thickness (m)						[1]			0.10
7.1.5	Initial Soil Water Content Fraction of Field Cap.						[1]			0.00
7.1.6	Minimum Depth to Water Table (m)						[1]			0.10
7.1.7	Maximum Depth to Water Table (m)						[1]			3.00
7.1.8	Initial Depth to Water Table (m)						[1]			0.10
7.1.9	Soil Weather Code						[1]			0.00
7.2.1	Depth from the surface to the bottom of the soil layer									
	.01 .15 .18 .48 .69 .91 1.17 1.52 1.93 2.00									
7.2.2	Bulk density of the soil layer									
	1.25 1.25 1.25 1.25 1.25 1.25 1.25 1.65 1.65 1.65									
7.2.3	Wilting point							[1]		
	.138 .138 .138 .152 .171 .171 .171 .119 .109 .175									
7.2.4	Field capacity							[1]		
	.273 .273 .273 .273 .294 .244 .304 .337 .340 .340									
7.2.5	Sand content (%)									
	1.9 1.9 1.9 1.9 1.0 1.0 1.0 5.5 7.3 2.5									
7.2.6	Silt content (%)									
	90.8 90.8 90.8 88.3 87.6 87.6 87.1 77.4 73.9 76.1									
7.2.7	Organic N concentration							[1]		
	520 520 520 270 410 410 380 280 130 120									
7.2.8	Soil pH									
	6.5 6.5 6.5 6.5 6.5 6.5 6.5 6.5 6.5 6.5									

[1] May be left blank or zero if unknown.

*** FORM 7 ***

EPIC DATA ASSEMBLY FORM

CONVENT SOIL

7.3.1	Sum of bases								[1]	
	4.5	4.5	4.5	5.27	5.4	5.4	5.2	6.7	7.8	12.3
7.3.2	Organic carbon									
	.54	.54	.54	.26	.44	.44	.40	.15	.13	.12
7.3.3	Calcium carbonate									
	0	0	0	0	0	0	0	0	0	0
7.3.4	Cation exchange capacity								[1]	
	5.3	5.3	5.3	6.2	6.3	6.3	6.1	7.9	9.2	14.5
7.3.5	Coarse fragment content								[1]	
	0	0	0	0	0	0	0	0	0	0
7.3.6	Nitrate concentration								[1]	
	2	2	1	1	1	1	1	1	1	1
7.3.7	Labile P concentration								[1]	
	30	30	10	10	10	10	10	10	10	10
7.3.8	Crop residue (%)								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.1	Bulk density (oven dry)								[1]	
	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.65	1.65	1.65
7.4.2	Phosphorus sorption ratio								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.3	Saturated conductivity								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.4	Subsurface flow travel time								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.5	Organic P concentration								[1]	
	0	0	0	0	0	0	0	0	0	0

[1] May be left blank or zero if unknown.

***** FORM 6 *****
EPIC DATA ASSEMBLY FORM
FALAYA SOIL

7.1 Soil Data

Enter soil access number or name to load from file and skip to Section 10.1 or enter zero and input below.

7.1.1	Soil albedo									0.17	
7.1.2	Maximum Number or Soil Layers							[1]		10.00	
7.1.3	Minimum Thickness of Maximum Layer (m)							[1]		0.10	
7.1.4	Minimum Soil Profile Thickness (m)							[1]		0.10	
7.1.5	Initial Soil Water Content Fraction of Field Cap.							[1]		0.00	
7.1.6	Minimum Depth to Water Table (m)							[1]		0.25	
7.1.7	Maximum Depth to Water Table (m)							[1]		3.00	
7.1.8	Initial Depth to Water Table (m)							[1]		0.50	
7.1.9	Soil Weather Code							[1]		0.00	
7.2.1	Depth from the surface to the bottom of the soil layer										
		.01	.15	.18	.48	.69	.91	1.17	1.52	1.93	2.00
7.2.2	Bulk density of the soil layer										
		1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.65	1.65	1.65
7.2.3	Wilting point									[1]	
		.138	.138	.138	.152	.171	.171	.171	.119	.109	.175
7.2.4	Field capacity									[1]	
		.273	.273	.273	.273	.294	.294	.304	.337	.340	.340
7.2.5	Sand content (%)										
		1.9	1.9	1.9	1.9	1.0	1.0	1.0	5.5	7.3	2.5
7.2.6	Silt content (%)										
		90.8	90.8	90.8	88.3	87.6	87.6	87.1	77.4	73.9	76.1
7.2.7	Organic N concentration									[1]	
		520	520	520	270	410	410	380	280	130	120
7.2.8	Soil pH										
		4.9	4.9	4.9	5.0	5.0	5.0	4.8	4.8	4.7	5.1

[1] May be left blank or zero if unknown.

*** FORM 7 ***

EPIC DATA ASSEMBLY FORM

FALAYA SOIL

7.3.1	Sum of bases								[1]	
	3.4	3.4	3.4	4.0	3.2	3.2	2.8	2.9	4.2	12.2
7.3.2	Organic carbon									
	.54	.54	.54	.26	.44	.44	.40	.15	.13	.12
7.3.3	Calcium carbonate									
	0	0	0	0	0	0	0	0	0	0
7.3.4	Cation exchange capacity								[1]	
	5.3	5.3	5.3	6.2	6.3	6.3	6.1	7.9	9.2	14.5
7.3.5	Coarse fragment content								[1]	
	0	0	0	0	0	0	0	0	0	0
7.3.6	Nitrate concentration								[1]	
	2	2	1	1	1	1	1	1	1	1
7.3.7	Labile P concentration								[1]	
	30	30	10	10	10	10	10	10	10	10
7.3.8	Crop residue (%)								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.1	Bulk density (oven dry)								[1]	
	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.65	1.65	1.65
7.4.2	Phosphorus sorption ratio								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.3	Saturated conductivity								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.4	Subsurface flow travel time								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.5	Organic P concentration								[1]	
	0	0	0	0	0	0	0	0	0	0

[1] May be left blank or zero if unknown.

***** FORM 6 *****
EPIC DATA ASSEMBLY FORM
GRENADA SOIL

7.1 Soil Data

Enter soil access number or name to load from file and skip to Section 10.1 or enter zero and input below.

7.1.1	Soil albedo									0.14	
7.1.2	Maximum Number of Soil Layers							[1]		10.00	
7.1.3	Minimum Thickness of Maximum Layer (m)							[1]		0.10	
7.1.4	Minimum Soil Profile Thickness (m)							[1]		0.10	
7.1.5	Initial Soil Water Content Fraction of Field Cap.							[1]		0.00	
7.1.6	Minimum Depth to Water Table (m)							[1]		1.00	
7.1.7	Maximum Depth to Water Table (m)							[1]		10.00	
7.1.8	Initial Depth to Water Table (m)							[1]		1.00	
7.1.9	Soil Weather Code							[1]		0.00	
7.2.1	Depth from the surface to the bottom of the soil layer										
		0.01	.15	.24	.33	.47	.61	.69	1.02	1.42	1.82
7.2.2	Bulk density of the soil layer										
		1.21	1.21	1.41	1.41	1.38	1.38	1.40	1.60	1.60	1.60
7.2.3	Wilting point									[1]	
		.147	.147	.154	.154	.206	.206	.188	.193	.191	.191
7.2.4	Field capacity									[1]	
		.273	.273	.283	.283	.360	.360	.349	.270	.264	.264
7.2.5	Sand content (%)										
		2.1	2.1	2.2	2.2	1.1	1.1	3.0	3.0	1.1	1.1
7.2.6	Silt content (%)										
		87.9	87.9	86.4	86.4	75.9	75.9	76.5	71.0	78.7	78.7
7.2.7	Organic N concentration									[1]	
		1767	1767	564	564	207	207	114	106	75	75
7.2.8	Soil pH										
		5.8	5.8	6.7	6.7	5.0	5.0	5.0	5.0	5.1	5.6

[1] May be left blank or zero if unknown.

*** FORM 7 ***

EPIC DATA ASSEMBLY FORM

GRENADA SOIL

7.3.1	Sum of bases								[1]	
		8.4	8.4	6.4	6.4	7.6	7.6	5.5	8.4	11.1 11.1
7.3.2	Organic carbon									
		1.77	1.77	.56	.56	.21	.21	.11	.11	.07 .07
7.3.3	Calcium carbonate									
		0	0	0	0	0	0	0	0	0
7.3.4	Cation exchange capacity								[1]	
		9.7	9.7	6.6	6.6	10.5	10.5	10.4	14.6	13.5 13.5
7.3.5	Coarse fragment content								[1]	
		0	0	0	0	0	0	0	0	0
7.3.6	Nitrate concentration								[1]	
		2	2	1	1	1	1	1	1	1
7.3.7	Labile P concentration								[1]	
		30	30	10	10	10	10	10	10	10
7.3.8	Crop residue (%)								[1]	
		0	0	0	0	0	0	0	0	0
7.4.1	Bulk density (oven dry)								[1]	
		1.21	1.21	1.41	1.41	1.38	1.38	1.40	1.60	1.60 1.60
7.4.2	Phosphorus sorption ratio								[1]	
		0	0	0	0	0	0	0	0	0
7.4.3	Saturated conductivity								[1]	
		0	0	0	0	0	0	0	0	0
7.4.4	Subsurface flow travel time								[1]	
		0	0	0	0	0	0	0	0	0
7.4.5	Organic P concentration								[1]	
		0	0	0	0	0	0	0	0	0

[1] May be left blank or zero if unknown.

***** FORM 6 *****
EPIC DATA ASSEMBLY FORM
LEXINGTON SOIL

7.1 Soil Data

Enter soil access number or name to load from file and skip to Section 10.1 or enter zero and input below.

7.1.1	Soil albedo								0.14	
7.1.2	Maximum Number of Soil Layers							[1]	9.00	
7.1.3	Minimum Thickness of Maximum Layer (m)							[1]	0.10	
7.1.4	Minimum Soil Profile Thickness (m)							[1]	0.10	
7.1.5	Initial Soil Water Content Fraction of Field Cap.							[1]	0.00	
7.1.6	Minimum Depth to Water Table (m)							[1]	10.00	
7.1.7	Maximum Depth to Water Table (m)							[1]	20.00	
7.1.8	Initial Depth to Water Table (m)							[1]	10.00	
7.1.9	Soil Weather Code							[1]	0.00	
7.2.1	Depth from the surface to the bottom of the soil layer									
		.01	.15	.25	.38	.56	.86	1.17	1.32	3.0
7.2.2	Bulk density of the soil layer									
		1.40	1.40	1.40	1.40	1.40	1.40	1.55	1.55	1.55
7.2.3	Wilting point									[1]
		0	0	0	0	0	0	0	0	0
7.2.4	Field capacity									[1]
		0	0	0	0	0	0	0	0	0
7.2.5	Sand content (%)									
		19.1	19.1	8.6	10.7	16.7	26.0	43.0	57.3	72.0
7.2.6	Silt content (%)									
		68.4	68.4	63.9	58.4	55.1	51.3	40.4	29.2	18.2
7.2.7	Organic N concentration									[1]
		720	720	610	500	410	320	320	320	320
7.2.8	Soil pH									
		5.2	5.2	5.3	5.2	5.0	5.1	5.2	5.2	5.2

[1] may be left blank or zero if unknown.

***** FORM 7 *****
EPIC DATA ASSEMBLY FORM
LEXINGTON SOIL

7.3.1	Sum of bases								[1]
	2.6	2.6	8.0	9.7	8.8	7.0	4.2	3.4	2.4
7.3.2	Organic carbon								
	.76	.76	.52	.33	.23	.16	.07	.03	.05
7.3.3	Calcium carbonate								
	0	0	0	0	0	0	0	0	0
7.3.4	Cation exchange capacity								[1]
	0	0	0	0	0	0	0	0	0
7.3.5	Coarse fragment content								[1]
	0	0	0	0	0	0	0	0	0
7.3.6	Nitrate concentration								[1]
	0	0	0	0	0	0	0	0	0
7.3.7	Labile P concentration								[1]
	0	0	0	0	0	0	0	0	0
7.3.8	Crop residue (%)								[1]
	0	0	0	0	0	0	0	0	0
7.4.1	Bulk density (oven dry)								[1]
	0	0	0	0	0	0	0	0	0
7.4.2	Phosphorus sorption ratio								[1]
	0	0	0	0	0	0	0	0	0
7.4.3	Saturated conductivity								[1]
	0	0	0	0	0	0	0	0	0
7.4.4	Subsurface flow travel time								[1]
	0	0	0	0	0	0	0	0	0
7.4.5	Organic P concentration								[1]
	0	0	0	0	0	0	0	0	0

[1] may be left blank or zero if unknown.

***** FORM 6 *****
EPIC DATA ASSEMBLY FORM
LORING SOIL

7.1 Soil Data

Enter soil access number or name to load from file and skip to Section 10.1 or enter zero and input below.

7.1.1	Soil albedo									0.14
7.1.2	Maximum Number or Soil Layers						[1]			10.00
7.1.3	Minimum Thickness of Maximum Layer (m)						[1]			0.10
7.1.4	Minimum Soil Profile Thickness (m)						[1]			0.10
7.1.5	Initial Soil Water Content Fraction of Field Cap.						[1]			0.00
7.1.6	Minimum Depth to Water Table (m)						[1]			1.00
7.1.7	Maximum Depth to Water Table (m)						[1]			15.00
7.1.8	Initial Depth to Water Table (m)						[1]			1.00
7.1.9	Soil Weather Code						[1]			0.00
7.2.1	Depth from the surface to the bottom of the soil layer									
	.01 .15 .23 .53 .69 .86 1.07 1.32 1.63 2.00									
7.2.2	Bulk density of the soil layer									
	1.45 1.45 1.45 1.45 1.45 1.60 1.60 1.60 1.60 1.55									
7.2.3	Wilting point								[1]	
	.130 .130 .206 .206 .206 .193 .176 .191 .190 .183									
7.2.4	Field capacity								[1]	
	.285 .285 .360 .344 .360 .270 .245 .265 .261 .258									
7.2.5	Sand content (%)									
	1.4 1.4 .7 .0 .7 1.1 1.7 1.2 1.1 2.0									
7.2.6	Silt content (%)									
	88.2 88.2 74.5 69.8 74.6 77.9 81.3 78.5 79.5 79.2									
7.2.7	Organic N concentration								[1]	
	736 736 510 440 330 120 100 80 80 80									
7.2.8	Soil pH									
	5.0 5.0 4.8 4.7 4.9 5.1 5.2 5.2 5.5 6.0									

[1] May be left blank or zero if unknown.

***** FORM 7 *****
EPIC DATA ASSEMBLY FORM
LORING SOIL

7.3.1	Sum of bases								[1]	
	1.6	1.6	3.6	5.0	3.8	3.5	4.1	6.5	11.4	11.2
7.3.2	Organic carbon									
	1.18	1.18	.43	.21	.13	.12	.10	.08	.08	.08
7.3.3	Calcium carbonate									
	0	0	0	0	0	0	0	0	0	0
7.3.4	Cation exchange capacity								[1]	
	6.3	6.3	9.7	12.8	11.7	10.5	9.6	11.5	12.2	11.3
7.3.5	Coarse fragment content								[1]	
	0	0	0	0	0	0	0	0	0	0
7.3.6	Nitrate concentration								[1]	
	2	2	1	1	1	1	1	1	1	1
7.3.7	Labile P concentration								[1]	
	30	30	10	10	10	10	10	10	10	10
7.3.8	Crop residue (%)								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.1	Bulk density (oven dry)								[1]	
	1.45	1.45	1.45	1.45	1.45	1.60	1.60	1.60	1.60	1.55
7.4.2	Phosphorus sorption ratio								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.3	Saturated conductivity								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.4	Subsurface flow travel time								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.5	Organic P concentration								[1]	
	0	0	0	0	0	0	0	0	0	0

[1] May be left blank or zero if unknown.

***** FORM 6 *****
EPIC DATA ASSEMBLY FORM
MEMPHIS SOIL

7.1 Soil Data

Enter soil access number or name to load from file and skip to Section 10.1 or enter zero and input below.

7.1.1	Soil albedo									0.14	
7.1.2	Maximum Number of Soil Layers							[1]		10.00	
7.1.3	Minimum Thickness of Maximum Layer (m)							[1]		0.10	
7.1.4	Minimum Soil Profile Thickness (m)							[1]		0.10	
7.1.5	Initial Soil Water Content Fraction of Field Cap.							[1]		0.00	
7.1.6	Minimum Depth to Water Table (m)							[1]		10.00	
7.1.7	Maximum Depth to Water Table (m)							[1]		20.00	
7.1.8	Initial Depth to Water Table (m)							[1]		10.00	
7.1.9	Soil Weather Code							[1]		0.00	
7.2.1	Depth from the surface to the bottom of the soil layer										
		.01	.15	.25	.36	.53	.71	.99	1.35	1.65	2.00
7.2.2	Bulk density of the soil layer										
		1.35	1.35	1.35	1.35	1.40	1.40	1.40	1.40	1.40	1.40
7.2.3	Wilting point									[1]	
		.216	.216	.234	.234	.206	.206	.206	.196	.185	.174
7.2.4	Field capacity									[1]	
		.356	.356	.358	.358	.360	.360	.358	.338	.316	.290
7.2.5	Sand content (%)										
		.9	.9	.8	.8	1.1	1.1	1.1	.9	1.0	.8
7.2.6	Silt content (%)										
		72.1	72.1	71.2	71.2	76.1	76.1	78.5	81.6	83.6	86.4
7.2.7	Organic N concentration									[1]	
		1077	1077	340	340	220	220	90	80	80	50
7.2.8	Soil pH										
		5.1	5.1	4.9	4.9	5.2	5.2	5.3	5.6	5.8	5.8

[1] May be left blank or zero if unknown.

***** FORM 7 *****
EPIC DATA ASSEMBLY FORM
MEMPHIS SOIL

7.3.1	Sum of bases								[1]	
		11.4	11.4	10.6	10.6	11.5	11.5	12.2	12.9	12.2 12.2
7.3.2	Organic carbon									
		1.34	1.34	.19	.19	.12	.12	.09	.08	.08 .05
7.3.3	Calcium carbonate									
		0	0	0	0	0	0	0	0	0
7.3.4	Cation exchange capacity									[1]
		17.4	17.4	16.3	16.3	14.7	14.7	14.2	13.7	12.9 12.4
7.3.5	Coarse fragment content									[1]
		0	0	0	0	0	0	0	0	0
7.3.6	Nitrate concentration									[1]
		2	2	1	1	1	1	1	1	1
7.3.7	Labile P concentration									[1]
		30	30	10	10	10	10	10	10	10
7.3.8	Crop residue (%)									[1]
		0	0	0	0	0	0	0	0	0
7.4.1	Bulk density (oven dry)									[1]
		1.35	1.35	1.35	1.35	1.40	1.40	1.40	1.40	1.40 1.40
7.4.2	Phosphorus sorption ratio									[1]
		0	0	0	0	0	0	0	0	0
7.4.3	Saturated conductivity									[1]
		0	0	0	0	0	0	0	0	0
7.4.4	Subsurface flow travel time									[1]
		0	0	0	0	0	0	0	0	0
7.4.5	Organic P concentration									[1]
		0	0	0	0	0	0	0	0	0

[1] May be left blank or zero if unknown.

*** FORM 6 ***

EPIC DATA ASSEMBLY FORM

PROVIDENCE SOIL

7.1	<u>Soil Data</u>									
	Enter soil access number or name to load from file and skip to Section 10.1 or enter zero and input below.									
7.1.1	Soil albedo									0.17
7.1.2	Maximum Number or Soil Layers								[1]	10.00
7.1.3	Minimum Thickness of Maximum Layer (m)								[1]	0.10
7.1.4	Minimum Soil Profile Thickness (m)								[1]	0.10
7.1.5	Initial Soil Water Content Fraction of Field Cap.								[1]	0.00
7.1.6	Minimum Depth to Water Table (m)								[1]	1.00
7.1.7	Maximum Depth to Water Table (m)								[1]	1.50
7.1.8	Initial Depth to Water Table (m)								[1]	1.00
7.1.9	Soil Weather Code								[1]	0.00
7.2.1	Depth from the surface to the bottom of the soil layer									
	.01	.08	.18	.23	.36	.58	.76	.96	1.35	1.52
7.2.2	Bulk density of the soil layer									
	.93	.93	1.47	1.47	1.47	1.47	1.47	1.65	1.9	1.9
7.2.3	Wilting point									
	0	0	0	0	0	0	0	0	0	0
7.2.4	Field capacity									
	0	0	0	0	0	0	0	0	0	0
7.2.5	Sand content (%)									
	17.5	17.5	14.7	11.2	8.9	7.6	10.0	28.4	50.9	59.2
7.2.6	Silt content (%)									
	73	73	74.2	74.3	70.2	62.8	65.3	56.1	34.5	26.8
7.2.7	Organic N concentration									
	1350	1350	440	320	290	310	270	270	270	270
7.2.8	Soil pH									
	5.3	5.3	5.0	5.1	5.1	5.2	5.3	5.5	5.4	5.4

[1] May be left blank or zero if unknown.

***** FORM 7 *****
EPIC DATA ASSEMBLY FORM
PROVIDENCE SOIL

7.3.1	Sum of bases								[1]	
	6.3	6.3	.09	1.9	3.6	4.6	4.6	4.1	2.3	2.8
7.3.2	Organic carbon									
	3.92	3.92	.84	.40	.23	.14	.10	.06	.02	.03
7.3.3	Calcium carbonate									
	0	0	0	0	0	0	0	0	0	0
7.3.4	Cation exchange capacity								[1]	
	14.2	14.2	6.0	6.3	7.7	11.4	10.4	6.7	5.1	5.0
7.3.5	Coarse fragment content								[1]	
	0	0	0	0	0	0	0	0	0	0
7.3.6	Nitrate concentration								[1]	
	0	0	0	0	0	0	0	0	0	0
7.3.7	Labile P concentration								[1]	
	0	0	0	0	0	0	0	0	0	0
7.3.8	Crop residue (%)								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.1	Bulk density (oven dry)								[1]	
	.93	.93	1.47	1.47	1.47	1.47	1.47	1.65	1.9	1.9
7.4.2	Phosphorus sorption ratio								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.3	Saturated conductivity								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.4	Subsurface flow travel time								[1]	
	0	0	0	0	0	0	0	0	0	0
7.4.5	Organic P concentration								[1]	
	0	0	0	0	0	0	0	0	0	0

[1] May be left blank or zero if unknown.

***** FORM 6 *****
EPIC DATA ASSEMBLY FORM
WAVERLY SOIL

7.1 Soil Data

Enter soil access number or name to load from file and skip to Section 10.1 or enter zero and input below.

7.1.1	Soil albedo										0.17
7.1.2	Maximum Number or Soil Layers								[1]		10.00
7.1.3	Minimum Thickness of Maximum Layer (m)								[1]		0.10
7.1.4	Minimum Soil Profile Thickness (m)								[1]		0.10
7.1.5	Initial Soil Water Content Fraction of Field Cap.								[1]		0.00
7.1.6	Minimum Depth to Water Table (m)								[1]		0.10
7.1.7	Maximum Depth to Water Table (m)								[1]		3.00
7.1.8	Initial Depth to Water Table (m)								[1]		0.10
7.1.9	Soil Weather Code								[1]		0.00
7.2.1	Depth from the surface to the bottom of the soil layer										
		.01	.15	.18	.48	.69	.91	1.17	1.52	1.93	2.0
7.2.2	Bulk density of the soil layer										
		1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.65	1.65	1.65
7.2.3	Wilting point									[1]	
		.138	.138	.138	.152	.171	.171	.171	.119	.109	.175
7.2.4	Field capacity									[1]	
		.273	.273	.273	.273	.294	.294	.304	.337	.340	.340
7.2.5	Sand content (%)										
		1.9	1.9	1.9	1.9	1.0	1.0	1.0	5.5	7.3	2.5
7.2.6	Silt content (%)										
		90.8	90.8	90.8	88.3	87.6	87.6	87.1	77.4	73.9	76.1
7.2.7	Organic N concentration									[1]	
		520	520	520	270	410	410	380	280	130	120
7.2.8	Soil pH										
		4.9	4.9	4.9	5.0	5.0	5.0	4.8	4.8	4.7	5.1

[1] May be left blank or zero if unknown.

*** FORM 7 ***

EPIC DATA ASSEMBLY FORM

WAVERLY SOIL

7.3.1	Sum of bases								[1]	
		3.4	3.4	3.4	4.0	3.2	3.2	2.8	2.9	4.2 12.2
7.3.2	Organic carbon									
		.54	.54	.54	.26	.44	.44	.40	.15	.13 .12
7.3.3	Calcium carbonate									
		0	0	0	0	0	0	0	0	0
7.3.4	Cation exchange capacity									[1]
		5.3	5.3	5.3	6.2	6.3	6.3	6.1	7.9	9.2 14.5
7.3.5	Coarse fragment content									[1]
		0	0	0	0	0	0	0	0	0
7.3.6	Nitrate concentration									[1]
		2	2	1	1	1	1	1	1	1
7.3.7	Labile P concentration									[1]
		30	30	10	10	10	10	10	10	10
7.3.8	Crop residue (%)									[1]
		0	0	0	0	0	0	0	0	0
7.4.1	Bulk density (oven dry)									[1]
		1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.65	1.65 1.65
7.4.2	Phosphorus sorption ratio									[1]
		0	0	0	0	0	0	0	0	0
7.4.3	Saturated conductivity									[1]
		0	0	0	0	0	0	0	0	0
7.4.4	Subsurface flow travel time									[1]
		0	0	0	0	0	0	0	0	0
7.4.5	Organic P concentration									[1]
		0	0	0	0	0	0	0	0	0

[1] May be left blank or zero if unknown.

APPENDIX C

EPIC WEATHER DATA ASSEMBLY FORMS

*****FORM*****
EPIC DATA ASSEMBLY FORM
WEATHER DATA

5.2.1	Average monthly maximum air temperature (celsius)										
7.3	9.9	15.3	21.6	26.2	30.1	32.2	31.8	28.6	26.6	15.6	9.9
5.2.2	Average monthly minimum air temperature (celsius)										
-3.6	-1.7	3.2	8.6	13.3	18.2	19.78	18.6	14.6	7.6	2.8	-1.2
5.2.3	Monthly standard deviation maximum air temperature (celsius)										[3,8]
10.5	10.9	11.2	12.2	13.4	13.0	14.8	14.1	13.4	12.6	11.5	11.3
5.2.4	Monthly standard deviation minimum air temperature (celsius)										
10.9	11.1	11.9	12.3	13.2	8.9	15.1	14.6	13.1	12.0	11.7	11.4
5.2.5	Average monthly precipitation (centimeters)										
111.3	112.3	133.4	125.7	132.3	110.0	108.7	88.4	94.5	78.0	115.1	1295
5.2.6	Monthly standard deviation of daily precipitation (centimeters)										
9.4	9.1	10.4	10.7	11.7	10.9	9.8	9.7	9.6	8.1	10.2	11.7
5.2.7	Monthly skew coefficient for daily precipitation (centimeters)										
0.13	0.09	0.10	0.12	0.12	0.12	0.12	0.13	0.13	0.14	0.10	0.12
5.3.1	Monthly probability of wet day after dry day										
.57	.62	.61	.69	.63	.63	.70	.69	.69	.72	.69	.58
5.3.2	Monthly probability of wet day after wet day										
.43	.38	.39	.32	.37	.37	.30	.31	.31	.28	.39	.42
5.3.3	Average number of days of rain per month										
8	7	9	8	7	6	6	5	5	4	7	7
5.3.4	Monthly maximum 0.5h rainfall for period of record (based on Nashville data)										
15.7	16.3	21.1	18.8	47.2	24.9	48.3	42.7	27.9	20.3	22.1	16.3
5.3.5	Monthly average daily solar radiation										
166	241	336	444	537	571	566	500	385	275	185	142

APPENDIX D
YIELD ADJUSTMENT CALCULATIONS

Crop yields for each soil representative of the 1976 time period were available in the literature. (Buntley and Bell, 1976) The 1976 published yields were adjusted to be representative of current yield potentials. The adjustment procedure used was as follows:

1. $TP = BY * AP$

2. $PY = TP/TA$

3. $FY = AY/PY$

4. $NY = FY * BY$

Where:

BY are 1976 yields, by soil type and crop (Buntley and Bell, 1976);

AP is acres, by soil type and crop (United States Department of Agriculture, 1982);

TP is total crop production;

TA is total acres - summed over soils by crop (United States Department of Agriculture, 1982);

PY is average production yield, based on 1976 yields;

AY is the 1984 - 1989 average crop yield;

FY is the ratio used to adjust the 1976 yields to current levels; and

NY is new crop yield.

APPENDIX E
EPIC RESULTS

Appendix Table E-1. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Adler Soil 2 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Hay Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	tons/ac.	\$/ac.
Corn	0	2	154				182
Corn	20	2	140				155
Corn	40	1	119				110
Corn	60	1	92				52
Corn	80	1	63				-12
Corn	100	0	32				-79
Corn-soybean	0	6	154	46			343
Corn-soybean	20	5	153	46			349
Corn-soybean	40	4	150	46			350
Corn-soybean	60	4	143	46			341
Corn-soybean	80	4	129	46			317
Corn-soybean	100	3	112	46			283
Corn-soyb-wht/soyb	0	10	154	46	52		590
Corn-soyb-wht/soyb	20	6	154	46	52		598
Corn-soyb-wht/soyb	40	4	153	46	52		604
Corn-soyb-wht/soyb	60	4	151	46	51		604
Corn-soyb-wht/soyb	80	3	144	46	50		593
Corn-soyb-wht/soyb	100	3	133	46	47		565
Soybean	0	34		46			148
Wheat	0	1			52		50
Wheat	20	1			47		38
Wheat	40	1			41		21
Wheat	60	1			34		0
Wheat	80	1			27		-20
Wheat	100	0			20		-41
Hay	0	0				3.5	27
Hay	20	0				3.1	8
Hay	40	0				2.6	-14
Hay	60	0				2.1	-40
Hay	80	0				1.5	-69
Hay	100	0				1.0	-99

Appendix Table E-2. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Adler Soil 2 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	\$/ac.
Corn	0	2	140			142
Corn	20	2	124			110
Corn	40	1	103			67
Corn	60	1	81			19
Corn	80	1	57			-32
Corn	100	0	32			-89
Corn-soybean	0	8	140	34		208
Corn-soybean	20	7	137	34		209
Corn-soybean	40	5	132	34		205
Corn-soybean	60	4	124	34		193
Corn-soybean	80	4	112	34		174
Corn-soybean	100	4	98	34		147
Corn-soyb-wht/soyb	0	10	140	34	53	404
Corn-soyb-wht/soyb	20	7	139	34	53	410
Corn-soyb-wht/soyb	40	6	138	34	52	413
Corn-soyb-wht/soyb	60	5	136	34	51	411
Corn-soyb-wht/soyb	80	4	130	34	48	398
Corn-soyb-wht/soyb	100	4	121	34	44	369
Soybean	0	40		34		65
Wheat	10	1			53	41
Wheat	20	1			48	27
Wheat	40	1			42	10
Wheat	60	1			35	-10
Wheat	80	0			27	-32
Wheat	100	0			19	-56

Appendix Table E-3. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Birds Soil 1 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Hay Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac	tons/ac.	\$/ac.
Corn	0	8	80				8
Corn	20	5	79				10
Corn	40	4	76				8
Corn	60	4	67				-7
Corn	80	3	49				-43
Corn	100	2	26				-92
Corn-soybean	0	15	80	36			109
Corn-soybean	20	12	80	36			117
Corn-soybean	40	9	79	36			125
Corn-soybean	60	7	78	36			129
Corn-soybean	80	5	74	36			127
Corn-soybean	100	4	66	36			116
Corn-soyb-wht/soyb	0	-	-	-	-		-
Corn-soyb-wht/soyb	20	-	-	-	-		-
Corn-soyb-wht/soyb	40	-	-	-	-		-
Corn-soyb-wht/soyb	60	-	-	-	-		-
Corn-soyb-wht/soyb	80	-	-	-	-		-
Corn-soyb-wht/soyb	100	-	-	-	-		-
Soybean	0	22		36			84
Wheat	0				-		-
Wheat	20				-		-
Wheat	40				-		-
Wheat	60				-		-
Wheat	80				-		-
Wheat	100				-		-
Hay	0	3				2.7	-16
Hay	20	2				2.5	-23
Hay	40	1				2.2	-36
Hay	60	1				1.9	-52
Hay	80	0				1.4	-73
Hay	100	0				0.9	-99

Appendix Table E-4. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Birds Soil 1 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	\$/ac.
Corn	0	5	79			-2
Corn	20	4	76			-4
Corn	40	4	69			-15
Corn	60	3	59			-34
Corn	80	3	44			-64
Corn	100	2	26			-100
Corn-soybean	0	12	79	36		76
Corn-soybean	20	10	79	36		82
Corn-soybean	40	8	78	36		88
Corn-soybean	60	7	75	36		91
Corn-soybean	80	6	71	36		88
Corn-soybean	100	5	64	36		79
Corn-soyb-wht/soyb	-	-	-	-		-
Corn-soyb-wht/soyb	-	-	-	-		-
Corn-soyb-wht/soyb	-	-	-	-		-
Corn-soyb-wht/soyb	-	-	-	-		-
Corn-soyb-wht/soyb	-	-	-	-		-
Corn-soyb-wht/soyb	-	-	-	-		-
Soybean	0	24		36		77
Wheat	-			-		-
Wheat	-			-		-
Wheat	-			-		-
Wheat	-			-		-
Wheat	-			-		-

Appendix Table E-5. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Calloway Soil 1 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Hay Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	tons/ac.	\$/ac.
Corn	0	15	117				94
Corn	20	11	115				96
Corn	40	7	107				82
Corn	60	5	88				41
Corn	80	4	62				-15
Corn	100	3	32				-79
Corn-soybean	0	32	117	42			232
Corn-soybean	20	29	116	42			239
Corn-soybean	40	24	115	42			244
Corn-soybean	60	21	112	42			244
Corn-soybean	80	17	103	42			231
Corn-soybean	100	15	88	42			203
Corn-soyb-wht/soyb	0	42	117	42	50		449
Corn-soyb-wht/soyb	20	33	117	42	50		457
Corn-soyb-wht/soyb	40	27	117	42	50		464
Corn-soyb-wht/soyb	60	22	116	42	48		466
Corn-soyb-wht/soyb	80	19	114	42	46		463
Corn-soyb-wht/soyb	100	15	109	42	44		448
Soybean	0	58		42			124
Wheat	0	8			50		44
Wheat	20	7			46		34
Wheat	40	5			42		21
Wheat	60	4			35		4
Wheat	80	3			29		-15
Wheat	100	2			21		-37
Hay	0	3				3.4	21
Hay	20	2				3.0	5
Hay	40	1				2.6	-15
Hay	60	0				2.1	-40
Hay	80	0				1.5	-67
Hay	100	0				0.9	-94

Appendix Table E-6. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Calloway Soil 1 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac	\$/ac.
Corn	0	13	117			88
Corn	20	10	110			76
Corn	40	7	95			48
Corn	60	5	77			9
Corn	80	4	56			-35
Corn	100	3	32			-85
Corn-soybean	0	29	117	42		201
Corn-soybean	20	25	116	42		207
Corn-soybean	40	21	114	42		210
Corn-soybean	60	19	109	42		206
Corn-soybean	80	16	99	42		189
Corn-soybean	100	14	85	42		165
Corn-soyb-wht/soyb	0	37	117	42	49	430
Corn-soyb-wht/soyb	20	31	117	42	47	433
Corn-soyb-wht/soyb	40	27	117	42	45	435
Corn-soyb-wht/soyb	60	23	116	42	42	430
Corn-soyb-wht/soyb	80	20	113	42	41	428
Corn-soyb-wht/soyb	100	17	108	42	37	412
Soybean	0	58		42		113
Wheat	0	9			49	26
Wheat	20	7			45	16
Wheat	40	5			39	2
Wheat	60	4			33	-15
Wheat	80	3			27	-34
Wheat	100	2			19	-56

Appendix Table E-7. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Calloway Soil 4 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Hay Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	tons/ac.	\$/ac.
Corn	0	12	111				80
Corn	20	8	108				80
Corn	40	5	99				63
Corn	60	4	80				23
Corn	80	4	56				-28
Corn	100	3	29				-86
Corn-soybean	0	21	111	36			232
Corn-soybean	20	18	111	36			239
Corn-soybean	40	15	110	36			244
Corn-soybean	60	13	106	36			244
Corn-soybean	80	11	96	36			231
Corn-soybean	100	9	82	36			203
Corn-soyb-wht/soyb	0	26	111	36	49		360
Corn-soyb-wht/soyb	20	26	111	36	49		368
Corn-soyb-wht/soyb	40	20	111	36	48		374
Corn-soyb-wht/soyb	60	16	110	36	47		378
Corn-soyb-wht/soyb	80	13	108	36	46		374
Corn-soyb-wht/soyb	100	11	108	36	43		373
Soybean	0	9		36			88
Wheat	0	11			49		40
Wheat	20	9			45		30
Wheat	40	7			40		16
Wheat	60	5			35		2
Wheat	80	4			28		-16
Wheat	100	3			22		-34
Hay	0	3				3.1	5
Hay	20	2				2.8	-8
Hay	40	1				2.4	-26
Hay	60	1				2.0	-47
Hay	80	0				1.5	-72
Hay	100	0				0.9	-97

Appendix Table E-8. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Calloway Soil 4 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	\$/ac.
Corn	0	9	107			64
Corn	20	7	98			49
Corn	40	6	84			20
Corn	60	4	67			-13
Corn	80	4	49			-50
Corn	100	3	29			-94
Corn-soybean	0	20	107	36		142
Corn-soybean	20	17	106	36		147
Corn-soybean	40	14	103	36		149
Corn-soybean	60	12	97	36		141
Corn-soybean	80	11	86	36		124
Corn-soybean	100	10	73	36		100
Corn-soyb-wht/soyb	0	21	107	36	49	337
Corn-soyb-wht/soyb	20	19	107	36	48	340
Corn-soyb-wht/soyb	40	16	106	36	45	340
Corn-soyb-wht/soyb	60	14	105	36	42	334
Corn-soyb-wht/soyb	80	12	101	36	39	322
Corn-soyb-wht/soyb	100	10	94	36	34	298
Soybean	0	45		36		78
Wheat	0	12			49	26
Wheat	20	10			45	16
Wheat	40	8			39	2
Wheat	60	6			33	-15
Wheat	80	4			27	-34
Wheat	100	2			21	-56

Appendix Table E-9. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Collins Soil 1 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat yield	Hay Yield	Rotation Net Rev.
	percent	lbs/ac.	bu./ac.	bu./ac.	bu./ac.	tons/ac.	\$/ac.
Corn	0	1	148				167
Corn	20	1	135				144
Corn	40	1	116				103
Corn	60	0	63				46
Corn	80	0	91				-39
Corn	100	0	32				-78
Corn-soybean	0	3	148	46			328
Corn-soybean	20	2	147	46			334
Corn-soybean	40	2	144	46			335
Corn-soybean	60	2	136	46			325
Corn-soybean	80	1	123	46			301
Corn-soybean	100	1	102	46			261
Corn-soyb-wht/soyb	0	6	148	46	52		576
Corn-soyb-wht/soyb	20	3	147	46	52		583
Corn-soyb-wht/soyb	40	2	146	46	52		588
Corn-soyb-wht/soyb	60	1	143	46	52		587
Corn-soyb-wht/soyb	80	1	134	46	50		570
Corn-soyb-wht/soyb	100	1	119	46	48		536
Soybean	0	27		46			148
Wheat	0	0			52		50
Wheat	20	0			48		40
Wheat	40	0			43		26
Wheat	60	0			37		8
Wheat	80	0			30		-12
Wheat	100	0			22		-35
Hay	0	0				3.5	26
Hay	20	0				3.1	8
Hay	40	0				2.6	-15
Hay	60	0				2.1	-41
Hay	80	0				1.5	-69
Hay	100	0				0.9	-96

Appendix Table E-10. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Collins Soil 1 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	\$/ac.
Corn	0	1	134			88
Corn	20	1	120			76
Corn	40	0	101			48
Corn	60	0	80			9
Corn	80	0	57			-35
Corn	100	0	32			-85
Corn-soybean	0	3	134	46		265
Corn-soybean	20	3	132	46		268
Corn-soybean	40	2	127	46		264
Corn-soybean	60	2	119	46		253
Corn-soybean	80	2	106	46		231
Corn-soybean	100	1	90	46		201
Corn-soyb-wht/soyb	0	4	134	46	53	533
Corn-soyb-wht/soyb	20	3	133	46	53	539
Corn-soyb-wht/soyb	40	2	132	46	53	542
Corn-soyb-wht/soyb	60	2	127	46	52	536
Corn-soyb-wht/soyb	80	2	120	46	50	521
Corn-soyb-wht/soyb	100	1	110	46	45	490
Soybean	0	30		46		137
Wheat	0	0			53	41
Wheat	20	0			49	29
Wheat	40	0			43	14
Wheat	60	0			36	-6
Wheat	80	0			29	-28
Wheat	100	0			21	-51

Appendix Table E-11. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Convent Soil 2 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Hay Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	tons/ac.	\$/ac.
Corn	0	6	123				109
Corn	20	5	113				90
Corn	40	4	98				60
Corn	60	4	76				15
Corn	80	3	52				-37
Corn	100	2	26				-92
Corn-soybean	0	12	123	38			328
Corn-soybean	20	11	119	38			334
Corn-soybean	40	10	111	38			335
Corn-soybean	60	8	100	38			325
Corn-soybean	80	7	85	38			301
Corn-soybean	100	5	68	38			261
Corn-soyb-wht/soyb	0	11	123	38	36		371
Corn-soyb-wht/soyb	20	9	121	38	35		372
Corn-soyb-wht/soyb	40	8	116	38	35		366
Corn-soyb-wht/soyb	60	6	108	38	34		352
Corn-soyb-wht/soyb	80	5	96	38	32		326
Corn-soyb-wht/soyb	100	4	80	38	29		288
Soybean	0	26		38			124
Wheat	0	1			36		-2
Wheat	20	1			33		-10
Wheat	40	1			29		-20
Wheat	60	1			25		-30
Wheat	80	1			20		-42
Wheat	100	1			16		-55
Hay	0	1				3.4	21
Hay	20	1				3.0	3
Hay	40	1				2.6	-18
Hay	60	0				2.1	-41
Hay	80	0				1.5	-68
Hay	100	0				0.9	-96

Appendix Table E-12. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Convent Soil 2 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	\$/ac.
Corn	0	5	111			74
Corn	20	4	99			52
Corn	40	4	83			20
Corn	60	4	56			-19
Corn	80	4	45			-61
Corn	100	3	25			-102
Corn-soybean	0	6	111	38		163
Corn-soybean	20	5	93	38		128
Corn-soybean	40	4	84	38		116
Corn-soybean	60	4	67	38		82
Corn-soybean	80	4	48	38		47
Corn-soybean	100	3	27	38		4
Corn-soyb-wht/soyb	0	11	111	38	37	331
Corn-soyb-wht/soyb	20	9	108	38	36	329
Corn-soyb-wht/soyb	40	8	103	38	35	322
Corn-soyb-wht/soyb	60	7	97	38	33	310
Corn-soyb-wht/soyb	80	6	88	38	30	288
Corn-soyb-wht/soyb	100	5	78	38	27	259
Soybean	0	27		38		100
Wheat	0	5			37	-11
Wheat	20	5			34	-20
Wheat	40	8			29	-31
Wheat	60	4			26	-39
Wheat	80	4			22	-52
Wheat	100	3			16	-66

Appendix Table E-13. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Falaya Soil 2 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Hay Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac	tons/ac.	\$/ac.
Corn	0	4	123				109
Corn	20	3	112				89
Corn	40	3	97				57
Corn	60	2	76				15
Corn	80	2	53				-34
Corn	100	2	28				-89
Corn-soybean	0	7	123	38			223
Corn-soybean	20	6	119	38			222
Corn-soybean	40	5	112	38			213
Corn-soybean	60	4	102	38			197
Corn-soybean	80	4	89	38			174
Corn-soybean	100	4	74	38			147
Corn-soyb-wht/soyb	0	5	123	38	36		57
Corn-soyb-wht/soyb	20	5	121	38	35		64
Corn-soyb-wht/soyb	40	4	118	38	34		69
Corn-soyb-wht/soyb	60	4	111	38	32		64
Corn-soyb-wht/soyb	80	4	101	38	30		37
Corn-soyb-wht/soyb	100	4	88	38	27		-9
Soybean	0	23		38			89
Wheat	0	1			36		-2
Wheat	20	1			29		-22
Wheat	40	1			25		-33
Wheat	60	1			20		-44
Wheat	80	1			16		-56
Wheat	100	0			12		-105
Hay	0	1				3.4	21
Hay	20	1				3.0	3
Hay	40	1				2.6	-17
Hay	60	0				2.0	-41
Hay	80	0				1.5	-68
Hay	100	0				0.9	-98

Appendix Table E-14. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Falaya Soil 2 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	\$/ac.
Corn	0	3	105			60
Corn	20	3	94			39
Corn	40	3	80			11
Corn	60	2	64			-20
Corn	80	2	47			-52
Corn	100	1	28			-96
Corn-soybean	0	6	105	38		149
Corn-soybean	20	5	100	38		145
Corn-soybean	40	5	93	38		137
Corn-soybean	60	4	85	38		126
Corn-soybean	80	4	75	38		110
Corn-soybean	100	4	65	38		94
Corn-soyb-wht/soyb	0	5	105	38	35	311
Corn-soyb-wht/soyb	20	5	103	38	34	309
Corn-soyb-wht/soyb	40	4	99	38	32	303
Corn-soyb-wht/soyb	60	4	94	38	30	292
Corn-soyb-wht/soyb	80	4	87	38	27	275
Corn-soyb-wht/soyb	100	4	80	38	23	254
Soybean	0	23		38		89
Wheat	0	2			35	-18
Wheat	20	1			31	-28
Wheat	40	1			31	-26
Wheat	60	1			24	-45
Wheat	80	1			19	-59
Wheat	100	1			14	-72

Appendix Table E-15. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Grenada Soil 3 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Hay Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	tons/ac.	\$/ac.
Corn	0	8	111				82
Corn	20	5	110				84
Corn	40	4	106				80
Corn	60	3	91				49
Corn	80	2	66				-4
Corn	100	2	37				-68
Corn-soybean	0	21	111	35			178
Corn-soybean	20	16	111	35			185
Corn-soybean	40	12	110	35			191
Corn-soybean	60	10	107	35			192
Corn-soybean	80	8	99	35			180
Corn-soybean	100	6	83	35			150
Corn-soyb-wht/soyb	0	21	111	35	52		360
Corn-soyb-wht/soyb	20	15	111	35	52		367
Corn-soyb-wht/soyb	40	11	111	35	51		372
Corn-soyb-wht/soyb	60	8	111	35	49		373
Corn-soyb-wht/soyb	80	5	96	35	42		323
Corn-soyb-wht/soyb	100	5	96	35	42		331
Soybean	0	46		35			82
Wheat	10	3			52		50
Wheat	20	2			49		42
Wheat	40	2			43		27
Wheat	60	1			38		13
Wheat	80	1			32		-6
Wheat	100	1			24		-27
Hay	0	1				3.1	5
Hay	20	1				2.8	-6
Hay	40	1				2.5	-21
Hay	60	0				2.1	-41
Hay	80	0				1.6	-66
Hay	100	0				1.0	-91

Appendix Table E-16. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Grenada Soil 3 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	\$/ac.
Corn	0	5	116			86
Corn	20	4	108			73
Corn	40	3	102			64
Corn	60	2	85			28
Corn	80	2	62			-19
Corn	100	1	38			-73
Corn-soybean	0	17	116	34		151
Corn-soybean	20	14	114	34		155
Corn-soybean	40	12	112	34		157
Corn-soybean	60	10	106	34		152
Corn-soybean	80	8	96	34		139
Corn-soybean	100	7	81	34		108
Corn-soyb-wht/soyb	0	17	116	34	52	344
Corn-soyb-wht/soyb	20	12	116	34	52	350
Corn-soyb-wht/soyb	40	10	115	34	50	350
Corn-soyb-wht/soyb	60	8	113	34	47	346
Corn-soyb-wht/soyb	80	6	109	34	44	331
Corn-soyb-wht/soyb	100	5	98	34	39	298
Soybean	0	44		34		65
Wheat	0	3			52	37
Wheat	20	2			48	28
Wheat	40	2			43	14
Wheat	60	1			37	-3
Wheat	80	1			30	-23
Wheat	100	1			23	-44

Appendix Table E-17. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Grenada Soil 7 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Hay Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	tons/ac.	\$/ac.
Corn	0	7	92				36
Corn	20	4	92				41
Corn	40	3	90				41
Corn	60	2	78				19
Corn	80	1	57				-27
Corn	100	1	30				-85
Corn-soybean	0	12	92	28			91
Corn-soybean	20	8	92	28			99
Corn-soybean	40	6	92	28			107
Corn-soybean	60	4	90	28			110
Corn-soybean	80	4	82	28			99
Corn-soybean	100	3	65	28			67
Corn-soyb-wht/soyb	0	12	92	28	48		218
Corn-soyb-wht/soyb	20	8	92	28	47		222
Corn-soyb-wht/soyb	40	5	92	28	44		222
Corn-soyb-wht/soyb	60	4	92	28	41		217
Corn-soyb-wht/soyb	80	3	72	28	30		144
Corn-soyb-wht/soyb	100	3	73	28	30		152
Soybean	0	28		28			41
Wheat	0	3			48		37
Wheat	20	2			44		27
Wheat	40	2			39		14
Wheat	60	1			34		-2
Wheat	80	1			27		-19
Wheat	100	1			20		-39
Hay	0	1				2.8	-10
Hay	20	1				2.6	-20
Hay	40	0				2.3	-33
Hay	60	0				1.9	-51
Hay	80	0				1.4	-73
Hay	100	0				0.9	-95

Appendix Table E-18. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Grenada Soil 7 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	\$/ac.
Corn	0	4	96			39
Corn	20	3	93			36
Corn	40	3	84			22
Corn	60	2	70			-7
Corn	80	1	30			-95
Corn	100	1	30			-91
Corn-soybean	0	8	96	28		68
Corn-soybean	20	7	95	28		74
Corn-soybean	40	6	94	28		78
Corn-soybean	60	4	87	28		71
Corn-soybean	80	4	78	28		58
Corn-soybean	100	4	63	28		31
Corn-soyb-wht/soyb	0	8	96	28	48	213
Corn-soyb-wht/soyb	20	6	96	28	46	213
Corn-soyb-wht/soyb	40	5	96	28	43	211
Corn-soyb-wht/soyb	60	4	94	28	38	200
Corn-soyb-wht/soyb	80	4	86	28	33	173
Corn-soyb-wht/soyb	100	3	74	28	27	133
Soybean	0	29		28		30
Wheat	0	3			48	24
Wheat	20	2			44	13
Wheat	40	2			39	0
Wheat	60	1			33	-16
Wheat	80	1			27	-35
Wheat	100	1			19	-55

Appendix Table E-19. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Lexington Soil 5 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Hay Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	tons/ac.	\$/ac.
Corn	0	12	123				109
Corn	20	7	123				114
Corn	40	5	120				113
Corn	60	4	107				87
Corn	80	4	82				33
Corn	100	3	51				-35
Corn-soybean	0	33	123	34			199
Corn-soybean	20	22	123	34			207
Corn-soybean	40	16	123	34			215
Corn-soybean	60	12	123	34			222
Corn-soybean	80	11	120	34			224
Corn-soybean	100	9	108	34			204
Corn-soyb-wht/soyb	0	36	123	34	53		378
Corn-soyb-wht/soyb	20	25	123	34	53		386
Corn-soyb-wht/soyb	40	16	123	34	53		394
Corn-soyb-wht/soyb	60	12	123	34	53		401
Corn-soyb-wht/soyb	80	10	121	34	51		400
Corn-soyb-wht/soyb	100	8	112	34	49		378
Soybean	0	55		34			77
Wheat	0	10			53		53
Wheat	20	9			51		50
Wheat	40	8			47		40
Wheat	60	7			42		36
Wheat	80	6			36		9
Wheat	100	5			29		-12
Hay	0	4				3.1	5
Hay	20	4				2.9	-4
Hay	40	3				2.6	-18
Hay	60	2				2.2	-35
Hay	80	1				1.7	-56
Hay	100	1				1.2	-79

Appendix Table E-20. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Lexington Soil 5 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	\$/ac.
Corn	0	8	126			109
Corn	20	8	125			111
Corn	40	6	118			101
Corn	60	4	102			68
Corn	80	4	78			16
Corn	100	4	49			-45
Corn-soybean	0	15	126	34		175
Corn-soybean	20	12	124	34		179
Corn-soybean	40	11	118	34		171
Corn-soybean	60	9	102	34		141
Corn-soybean	80	7	78	34		94
Corn-soybean	100	6	51	34		36
Corn-soyb-wht/soyb	0	31	126	34	55	378
Corn-soyb-wht/soyb	20	21	126	34	55	386
Corn-soyb-wht/soyb	40	16	126	34	55	392
Corn-soyb-wht/soyb	60	13	125	34	54	395
Corn-soyb-wht/soyb	80	12	122	34	51	388
Corn-soyb-wht/soyb	100	10	112	34	47	358
Soybean	0	55		34		66
Wheat	0	10			55	47
Wheat	20	9			52	41
Wheat	40	8			48	30
Wheat	60	7			42	14
Wheat	80	6			36	-5
Wheat	100	5			28	-27

Appendix Table E-21. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Lexington Soil 12 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Hay Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac	tons/ac.	\$/ac.
Corn	0	28	86				22
Corn	20	31	86				27
Corn	40	12	86				33
Corn	60	5	86				37
Corn	80	4	78				23
Corn	100	3	52				-32
Corn-soybean	0	33	86	24			53
Corn-soybean	20	25	86	24			61
Corn-soybean	40	16	86	24			69
Corn-soybean	60	8	86	24			76
Corn-soybean	80	4	86	24			84
Corn-soybean	100	4	83	24			84
Corn-soyb-wht/soyb	0	28	86	24	47		154
Corn-soyb-wht/soyb	20	19	86	24	47		161
Corn-soyb-wht/soyb	40	11	86	24	47		169
Corn-soyb-wht/soyb	60	4	86	24	46		174
Corn-soyb-wht/soyb	80	4	86	24	44		173
Corn-soyb-wht/soyb	100	3	82	24	39		159
Soybean	0	33		24			17
Wheat	0	4			47		34
Wheat	20	4			45		31
Wheat	40	4			43		25
Wheat	60	3			38		14
Wheat	80	3			33		-1
Wheat	100	2			27		-19
Hay	0	2				2.5	-26
Hay	20	2				2.4	-28
Hay	40	1				2.2	-35
Hay	60	1				2.0	-46
Hay	80	1				1.6	-62
Hay	100	0				1.2	-84

Appendix Table E-22. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Lexington Soil 12 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	\$/ac.
Corn	0	12	89			22
Corn	20	4	89			27
Corn	40	3	89			32
Corn	60	2	85			27
Corn	80	2	70			-1
Corn	100	1	48			-49
Corn-soybean	0	25	89	24		28
Corn-soybean	20	18	89	24		36
Corn-soybean	40	11	89	24		43
Corn-soybean	60	6	89	24		51
Corn-soybean	80	4	88	24		58
Corn-soybean	100	4	83	24		54
Corn-soyb-wht/soyb	0	21	89	24	48	149
Corn-soyb-wht/soyb	20	13	89	24	48	157
Corn-soyb-wht/soyb	40	8	89	24	47	162
Corn-soyb-wht/soyb	60	5	89	24	46	164
Corn-soyb-wht/soyb	80	4	88	24	42	161
Corn-soyb-wht/soyb	100	4	84	24	37	142
Soybean	0	34		24		6
Wheat	0	4		48		24
Wheat	20	4		46		20
Wheat	40	4		42		11
Wheat	60	4		38		-1
Wheat	80	3		32		-17
Wheat	100	2		26		-35

Appendix Table E-23. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Loring Soil 3 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Hay Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	tons/ac.	\$/ac.
Corn	0	5	129				124
Corn	20	4	126				121
Corn	40	3	112				94
Corn	60	2	89				45
Corn	80	2	61				-15
Corn	100	1	31				-81
Corn-soybean	0	14	129	40			250
Corn-soybean	20	12	129	40			257
Corn-soybean	40	9	128	40			263
Corn-soybean	60	7	125	40			263
Corn-soybean	80	5	114	40			245
Corn-soybean	100	4	92	40			202
Corn-soyb-wht/soyb	0	28	129	40	56		474
Corn-soyb-wht/soyb	20	20	129	40	56		482
Corn-soyb-wht/soyb	40	13	129	40	56		490
Corn-soyb-wht/soyb	60	10	128	40	56		495
Corn-soyb-wht/soyb	80	7	124	40	55		491
Corn-soyb-wht/soyb	100	4	110	40	54		463
Soybean	0	45		40			112
Wheat	10	8			56		63
Wheat	20	4			56		65
Wheat	40	3			54		62
Wheat	60	2			50		51
Wheat	80	1			42		28
Wheat	100	1			32		-3
Hay	0	1				3.4	21
Hay	20	1				3.0	4
Hay	40	0				2.5	-22
Hay	60	0				2.0	-43
Hay	80	0				1.5	-70
Hay	100	0				1.0	-97

Appendix Table E-24. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Loring Soil 3 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	\$/ac.
Corn	0	5	126			109
Corn	20	4	115			89
Corn	40	4	98			55
Corn	60	2	79			13
Corn	80	2	56			-34
Corn	100	1	31			-88
Corn-soybean	0	14	126	41		216
Corn-soybean	20	12	125	41		222
Corn-soybean	40	10	122	41		223
Corn-soybean	60	8	114	41		211
Corn-soybean	80	7	100	41		187
Corn-soybean	100	5	82	41		151
Corn-soyb-wht/soyb	0	21	126	41	58	470
Corn-soyb-wht/soyb	20	16	126	41	58	479
Corn-soyb-wht/soyb	40	12	126	41	58	185
Corn-soyb-wht/soyb	60	9	124	41	58	488
Corn-soyb-wht/soyb	80	6	118	41	57	480
Corn-soyb-wht/soyb	100	4	105	41	55	450
Soybean	0	45		41		107
Wheat	0	7			58	57
Wheat	20	4			57	57
Wheat	40	3			55	52
Wheat	60	3			55	54
Wheat	80	1			41	13
Wheat	100	1			30	-20

Appendix Table E-25. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Loring Soil 6 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Hay Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	tons/ac.	\$/ac.
Corn	0	4	111				80
Corn	20	2	108				80
Corn	40	2	98				61
Corn	60	1	79				20
Corn	80	1	54				-33
Corn	100	1	27				-91
Corn-soybean	0	11	111	36			182
Corn-soybean	20	8	111	36			189
Corn-soybean	40	6	110	36			196
Corn-soybean	60	5	106	36			195
Corn-soybean	80	4	94	36			174
Corn-soybean	100	4	74	36			135
Corn-soyb-wht/soyb	0	12	111	36	51		474
Corn-soyb-wht/soyb	20	8	111	36	50		482
Corn-soyb-wht/soyb	40	6	110	36	49		490
Corn-soyb-wht/soyb	60	4	109	36	47		495
Corn-soyb-wht/soyb	80	4	102	36	43		491
Corn-soyb-wht/soyb	100	3	86	36	37		463
Soybean	0	34		36			88
Wheat	0	2			51		47
Wheat	20	1			47		36
Wheat	40	1			42		21
Wheat	60	1			35		3
Wheat	80	1			28		-17
Wheat	100	1			20		-40
Hay	0	1				3.1	5
Hay	20	1				2.8	-9
Hay	40	0				2.5	-20
Hay	60	0				1.9	-52
Hay	80	0				1.4	-74
Hay	100	0				0.9	-100

Appendix Table E-26. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Loring Soil 6 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	\$/ac.
Corn	0	3	110			72
Corn	20	2	100			54
Corn	40	2	86			25
Corn	60	2	69			-10
Corn	80	1	49			-52
Corn	100	1	27			-98
Corn-soybean	0	9	110	36		149
Corn-soybean	20	7	109	36		154
Corn-soybean	40	6	105	36		152
Corn-soybean	60	5	96	36		140
Corn-soybean	80	4	83	36		117
Corn-soybean	100	4	67	36		87
Corn-soyb-wht/soyb	0	8	110	36	51	351
Corn-soyb-wht/soyb	20	6	110	36	50	354
Corn-soyb-wht/soyb	40	5	109	36	47	352
Corn-soyb-wht/soyb	60	4	105	36	44	341
Corn-soyb-wht/soyb	80	4	97	36	39	313
Corn-soyb-wht/soyb	100	4	84	36	37	282
Soybean	0	34		36		78
Wheat	0	1			51	34
Wheat	20	2			47	22
Wheat	40	1			41	8
Wheat	60	1			35	-11
Wheat	80	1			28	-32
Wheat	100	1			20	-55

Appendix Table E-27. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Loring Soil 10 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Hay Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac	tons/ac.	\$/ac.
Corn	0	8	80				7
Corn	20	3	80				12
Corn	40	2	79				17
Corn	60	1	72				5
Corn	80	1	52				-37
Corn	100	1	25				-95
Corn-soybean	0	15	80	23			32
Corn-soybean	20	8	80	23			40
Corn-soybean	40	5	80	23			48
Corn-soybean	60	4	79	23			54
Corn-soybean	80	3	73	23			48
Corn-soybean	100	2	55	23			13
Corn-soyb-wht/soyb	0	12	80	23	46		123
Corn-soyb-wht/soyb	20	8	80	23	44		125
Corn-soyb-wht/soyb	40	5	80	23	42		124
Corn-soyb-wht/soyb	60	4	80	23	38		119
Corn-soyb-wht/soyb	80	3	75	23	32		97
Corn-soyb-wht/soyb	100	2	58	23	26		46
Soybean	0	21		23			17
Wheat	0	2			46		31
Wheat	20	2			42		21
Wheat	40	1			37		8
Wheat	60	1			31		-10
Wheat	80	1			25		-28
Wheat	100	1			17		-49
Hay	0	1				2.9	-5
Hay	20	1				2.6	-18
Hay	40	0				2.3	-34
Hay	60	0				1.8	-55
Hay	80	0				1.3	-78
Hay	100	0				0.8	-103

Appendix Table E-28. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Loring Soil 10 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	\$/ac.
Corn	0	3	84			10
Corn	20	2	83			13
Corn	40	2	76			3
Corn	60	2	63			-24
Corn	80	1	46			56
Corn	100	1	25			-102
Corn-soybean	0	6	84	21		-2
Corn-soybean	20	5	84	21		-6
Corn-soybean	40	4	83	21		-12
Corn-soybean	60	4	78	21		-7
Corn-soybean	80	3	67	21		-10
Corn-soybean	100	2	51	21		-40
Corn-soyb-wht/soyb	0	7	84	21	46	-95
Corn-soyb-wht/soyb	20	5	84	21	44	-94
Corn-soyb-wht/soyb	40	4	83	21	40	-87
Corn-soyb-wht/soyb	60	3	80	21	35	-75
Corn-soyb-wht/soyb	80	3	70	21	30	-42
Corn-soyb-wht/soyb	100	2	55	21	23	-7
Soybean	0	20		21		11
Wheat	0	3			46	18
Wheat	20	2			42	8
Wheat	40	1			37	-7
Wheat	60	1			31	-23
Wheat	80	1			24	-44
Wheat	100	1			17	-65

Appendix Table E-29. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Memphis Soil 3 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Hay Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	tons/ac.	\$/ac.
Corn	0	13	135				138
Corn	20	9	128				125
Corn	40	6	111				92
Corn	60	4	87				40
Corn	80	4	58				-22
Corn	100	4	28				-89
Corn-soybean	0	31	135	40			264
Corn-soybean	20	27	133	40			267
Corn-soybean	40	22	128	40			263
Corn-soybean	60	19	118	40			247
Corn-soybean	80	16	102	40			217
Corn-soybean	100	12	82	40			177
Corn-soyb-wht/soyb	0	37	135	40	54		482
Corn-soyb-wht/soyb	20	31	135	40	53		486
Corn-soyb-wht/soyb	40	27	134	40	53		489
Corn-soyb-wht/soyb	60	22	127	40	51		476
Corn-soyb-wht/soyb	80	19	116	40	48		448
Corn-soyb-wht/soyb	100	15	99	40	43		402
Soybean	0	61		40			112
Wheat	0	19			54		57
Wheat	20	16			49		46
Wheat	40	13			43		26
Wheat	60	11			36		6
Wheat	80	8			28		-17
Wheat	100	6			20		-42
Hay	0	7				3.4	21
Hay	20	4				3.0	4
Hay	40	3				2.6	-18
Hay	60	2				2.1	-42
Hay	80	1				1.5	-68
Hay	100	0				0.9	-95

Appendix Table E-30. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Memphis Soil 3 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn yield	Soybean yield	Wheat yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	\$/ac.
Corn	0	14	131			121
Corn	20	11	120			100
Corn	40	8	102			64
Corn	60	6	80			17
Corn	80	4	54			-38
Corn	100	4	27			-98
Corn-soybean	0	32	131	40		222
Corn-soybean	20	28	127	40		220
Corn-soybean	40	24	119	40		210
Corn-soybean	60	21	107	40		189
Corn-soybean	80	17	91	40		158
Corn-soybean	100	14	73	40		124
Corn-soyb-wht/soyb	0	39	131	40	52	451
Corn-soyb-wht/soyb	20	35	130	40	50	451
Corn-soyb-wht/soyb	40	30	126	40	48	443
Corn-soyb-wht/soyb	60	26	119	40	45	424
Corn-soyb-wht/soyb	80	22	108	40	40	391
Corn-soyb-wht/soyb	100	19	93	40	35	345
Soybean	0	60		40		101
Wheat	0	20			52	37
Wheat	20	16			47	23
Wheat	40	13			41	6
Wheat	60	11			34	-14
Wheat	80	8			26	-36
Wheat	100	5			18	-61

Appendix Table E-31. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Memphis Soil 6 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Hay Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	tons/ac.	\$/ac.
Corn	0	15	117				95
Corn	20	10	116				98
Corn	40	5	111				91
Corn	60	4	94				55
Corn	80	3	65				-7
Corn	100	3	31				-81
Corn-soybean	0	30	117	36			196
Corn-soybean	20	23	117	36			204
Corn-soybean	40	19	116	36			211
Corn-soybean	60	14	114	36			213
Corn-soybean	80	12	105	36			200
Corn-soybean	100	9	87	36			165
Corn-soyb-wht/soyb	0	36	117	36	50		378
Corn-soyb-wht/soyb	20	26	117	36	50		385
Corn-soyb-wht/soyb	40	20	117	36	49		391
Corn-soyb-wht/soyb	60	16	116	36	47		391
Corn-soyb-wht/soyb	80	12	112	36	45		381
Corn-soyb-wht/soyb	100	10	100	36	40		347
Soybean	0	52	36				88
Wheat	0	13			50		44
Wheat	20	11			46		34
Wheat	40	9			41		18
Wheat	60	7			34		0
Wheat	80	6			27		-22
Wheat	100	4			19		-45
Hay	0	5				3.2	11
Hay	20	4				2.9	-5
Hay	40	3				2.4	-24
Hay	60	1				2.0	-47
Hay	80	1				1.4	-75
Hay	100	0				0.9	-98

Appendix Table E-32. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Memphis Soil 6 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	\$/ac.
Corn	0	12	120			95
Corn	20	9	117			93
Corn	40	6	106			73
Corn	60	4	87			33
Corn	80	4	61			-24
Corn	100	3	30			-90
Corn-soybean	0	28	120	36		172
Corn-soybean	20	22	120	36		179
Corn-soybean	40	19	117	36		182
Corn-soybean	60	15	111	36		176
Corn-soybean	80	12	99	36		154
Corn-soybean	100	11	80	36		119
Corn-soyb-wht/soyb	0	33	120	36	50	371
Corn-soyb-wht/soyb	20	27	120	36	49	375
Corn-soyb-wht/soyb	40	22	118	36	44	361
Corn-soyb-wht/soyb	60	19	118	36	44	369
Corn-soyb-wht/soyb	80	15	112	36	39	349
Corn-soyb-wht/soyb	100	12	97	36	34	309
Soybean	0	51		36		77
Wheat	0	13			50	31
Wheat	20	12			46	19
Wheat	40	9			40	3
Wheat	60	7			33	-15
Wheat	80	5			26	-37
Wheat	100	4			18	-62

Appendix Table E-33. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Memphis Soil 12 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Hay Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	tons/ac.	\$/ac.
Corn	0	20	92				37
Corn	20	6	92				42
Corn	40	3	91				45
Corn	60	2	83				30
Corn	80	1	60				-19
Corn	100	1	27				-91
Corn-soybean	0	20	92	16			-20
Corn-soybean	20	12	92	16			-28
Corn-soybean	40	7	92	16			-35
Corn-soybean	60	5	89	16			-36
Corn-soybean	80	4	77	16			-15
Corn-soybean	100	3	51	16			-38
Corn-soyb-wht/soyb	0	17	92	16	40		-50
Corn-soyb-wht/soyb	20	10	92	16	39		-55
Corn-soyb-wht/soyb	40	6	92	16	38		-58
Corn-soyb-wht/soyb	60	4	88	16	35		-47
Corn-soyb-wht/soyb	80	3	74	16	29		-5
Corn-soyb-wht/soyb	100	2	49	16	22		-72
Soybean	0	24		16			-30
Wheat	0	6			40		11
Wheat	20	4			38		7
Wheat	40	3			35		-1
Wheat	60	1			29		-16
Wheat	80	1			23		-34
Wheat	100	1			15		-56
Hay	0	3				2.3	-37
Hay	20	2				2.2	-42
Hay	40	2				1.9	-52
Hay	60	1				1.6	-66
Hay	80	1				1.2	-85
Hay	100	0				0.7	-107

Appendix Table E-34. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Memphis Soil 12 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	\$/ac.
Corn	0	7	96			39
Corn	20	4	95			42
Corn	40	3	91			37
Corn	60	2	77			9
Corn	80	1	55			-38
Corn	100	1	27			-98
Corn-soybean	0	12	96	16		3
Corn-soybean	20	9	96	16		4
Corn-soybean	40	6	94	16		8
Corn-soybean	60	4	88	16		1
Corn-soybean	80	4	73	16		-25
Corn-soybean	100	3	51	16		-65
Corn-soyb-wht/soyb	0	12	96	16	41	48
Corn-soyb-wht/soyb	20	8	95	16	40	50
Corn-soyb-wht/soyb	40	5	93	16	38	47
Corn-soyb-wht/soyb	60	4	86	16	34	26
Corn-soyb-wht/soyb	80	4	71	16	29	-20
Corn-soyb-wht/soyb	100	3	50	16	21	-85
Soybean	0	24		16		-41
Wheat	0	5			41	2
Wheat	20	4			39	-4
Wheat	40	4			35	-14
Wheat	60	3			29	-29
Wheat	80	3			22	-48
Wheat	100	2			15	-71

Appendix Table E-35. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Providence Soil 6 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Hay Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	tons/ac.	\$/ac.
Corn	0	1	92				36
Corn	20	0	92				41
Corn	40	0	90				41
Corn	60	0	76				15
Corn	80	0	54				-34
Corn	100	0	26				-93
Corn-soybean	0	12	92	24			67
Corn-soybean	20	4	92	24			75
Corn-soybean	40	2	92	24			83
Corn-soybean	60	2	91	24			90
Corn-soybean	80	1	85	24			83
Corn-soybean	100	1	67	24			47
Corn-soyb-wht/soyb	0	11	92	24	42		151
Corn-soyb-wht/soyb	20	4	92	24	42		159
Corn-soyb-wht/soyb	40	2	92	24	41		166
Corn-soyb-wht/soyb	60	1	92	24	40		167
Corn-soyb-wht/soyb	80	1	88	24	36		155
Corn-soyb-wht/soyb	100	1	74	24	30		110
Soybean	0	19		24			17
Wheat	0	0			42		17
Wheat	20	0			39		11
Wheat	40	0			35		0
Wheat	60	0			30		-14
Wheat	80	0			24		-32
Wheat	100	0			17		-52
Hay	0	0				3.0	-26
Hay	20	0				2.7	-36
Hay	40	0				2.4	-49
Hay	60	0				1.9	-53
Hay	80	0				1.4	-77
Hay	100	0				0.8	-106

Appendix Table E-36. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Providence Soil 6 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	\$/ac.
Corn	0	0	96			39
Corn	20	0	92			35
Corn	40	0	83			17
Corn	60	0	67			-14
Corn	80	0	48			-54
Corn	100	0	26			-100
Corn-soybean	0	4	96	24		44
Corn-soybean	20	2	96	24		52
Corn-soybean	40	2	95	24		58
Corn-soybean	60	1	92	24		58
Corn-soybean	80	1	81	24		41
Corn-soybean	100	1	65	24		11
Corn-soyb-wht/soyb	0	4	96	24	43	149
Corn-soyb-wht/soyb	20	2	96	24	43	155
Corn-soyb-wht/soyb	40	2	96	24	41	158
Corn-soyb-wht/soyb	60	1	94	24	39	154
Corn-soyb-wht/soyb	80	1	88	24	34	133
Corn-soyb-wht/soyb	100	1	75	24	28	99
Soybean	0	17		24	6	6
Wheat	0	0			43	8
Wheat	20	0			40	0
Wheat	40	0			35	-12
Wheat	60	0			29	-28
Wheat	80	0			23	-47
Wheat	100	0			15	-68

Appendix Table E-37. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Waverly Soil 2 Percent Slope, Conventional Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Hay Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	tons/ac.	\$/ac.
Corn	0	12	68				-22
Corn	20	6	67				-17
Corn	40	4	66				-14
Corn	60	3	62				-20
Corn	80	3	48				-90
Corn	100	3	26				-94
Corn-soybean	0	12	68	32			57
Corn-soybean	20	6	67	32			64
Corn-soybean	40	4	66	32			69
Corn-soybean	60	3	60	32			64
Corn-soybean	80	3	46	32			37
Corn-soybean	100	2	23	32			-9
Corn-soyb-wht/soyb	-	-	-	-			-
Corn-soyb-wht/soyb	-	-	-	-			-
Corn-soyb-wht/soyb	-	-	-	-			-
Corn-soyb-wht/soyb	-	-	-	-			-
Corn-soyb-wht/soyb	-	-	-	-			-
Corn-soyb-wht/soyb	-	-	-	-			-
Soybean	0	21		32			65
Wheat	0	-	-	-			-
Wheat	20	-	-	-			-
Wheat	40	-	-	-			-
Wheat	60	-	-	-			-
Wheat	80	-	-	-			-
Wheat	100	-	-	-			-
Hay	0	2				2.5	-26
Hay	20	1				2.3	-36
Hay	40	1				2.0	-49
Hay	60	0				1.8	-53
Hay	80	0				1.3	-77
Hay	100	0				0.7	-105

Appendix Table E-38. Crop Yield and Rotation Net Revenue Responses to Changes in Fertilizer Application - Waverly Soil 2 Percent Slope, Conservation Tillage.

Rotation	Fert. Reduction	Nitrate Leaching	Corn Yield	Soybean Yield	Wheat Yield	Rotation Net Rev.
	percent	lbs./ac.	bu./ac.	bu./ac.	bu./ac.	\$/ac.
Corn	0	6	69			-25
Corn	20	4	67			-24
Corn	40	4	64			-27
Corn	60	3	56			-41
Corn	80	3	43			-66
Corn	100	2	26			-101
Corn-soybean	0	12	69	32		28
Corn-soybean	20	10	69	32		36
Corn-soybean	40	7	69	32		43
Corn-soybean	60	6	68	32		49
Corn-soybean	80	5	65	32		50
Corn-soybean	100	4	59	32		45
Corn-soyb-wht/soyb	0	-	-	-	-	-
Corn-soyb-wht/soyb	20	-	-	-	-	-
Corn-soyb-wht/soyb	40	-	-	-	-	-
Corn-soyb-wht/soyb	60	-	-	-	-	-
Corn-soyb-wht/soyb	80	-	-	-	-	-
Corn-soyb-wht/soyb	100	-	-	-	-	-
Soybean	0	21		32		54
Wheat	0				-	-
Wheat	20				-	-
Wheat	40				-	-
Wheat	60				-	-
Wheat	80				-	-
Wheat	100				-	-

VITA

Gary Cole was born in Hanley Falls, Minnesota. He attended and graduated from Cottonwood High School in May, 1974. His undergraduate education was obtained at Southwest State University. Bachelor of Arts degrees in Agricultural Business Management and Business Administration and Management were received in the spring of 1978.

In the fall of 1978 he accepted a research assistantship and began graduate study in agricultural economics at North Dakota State University. A Master's degree in Agricultural Economics was awarded in 1981. Furthering his education, a Master's degree in Economics was obtained from Iowa State University in 1987. Interest in agriculture, economics and resource economic research resulted in the continuation of his graduate education at the University of Tennessee. His studies focused on agriculture and resource economics in the Department of Agricultural Economics and Rural Sociology. A Doctor of Philosophy degree in Agricultural Economics, with a resource economic concentration, was conferred in May 1991.

The author is a member of the Phi Kappa Phi and Gamma Sigma Delta honor societies. Gary received an outstanding graduate student award in 1981.

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