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# A Case Study of Investment in Agricultural Sustainability: Adoption and Policy Issues for Nitrogen Pollution Control in the Chesapeake Bay Drainage

by

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Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy
in
Agricultural Economics

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December, 1988

Blacksburg, Virginia

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## (ABSTRACT)

Nutrient loadings to the Chesapeake Bay are a source of concern for water quality agencies. In particular, excess nitrogen loadings from agricultural production activities threaten water quality in the Bay. Questions have been raised about how effectively traditional BMPs can control nitrogen loss from crop production. This study examines agricultural nitrogen pollution control from an input management perspective. Using an economic and physical model, seven production systems and nitrogen management strategies are compared in terms of input use, profitability, and nitrogen loss potential. Results suggest that several of the production systems will reduce residual nitrogen without reducing profits. However, it is recognized that factors in addition to profitability will influence producers' nitrogen management decisions. Therefore, using the results of a farmer survey, adoption models are estimated to examine the impact of production system characteristics and producer characteristics on the decision to use an alternative production system and nitrogen management strategy. Finally, a sensitivity analysis is conducted to examine the impact of alternative policy tools on adoption incentives. Both financial incentives and education and information programs are found to be important tools for influencing producers' decisions. Producers' interest in the alternative systems and desire for information on the systems suggest that agricultural research will contribute by assuring that producers have access to adequate information on the alternative systems.

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The first step is to measure whatever can be easily measured. This is okay as far as it goes. The second step is to disregard that which can't be measured or give it an arbitrary quantitative value. This is artificial and misleading. The third step is to presume that what can't be measured easily really isn't very important. This is blindness. The fourth step is to say that what can't be easily measured really doesn't exist. This is suicide.

> Daniel Yankelovich as quoted by Adam Smith (pseudonym for G.J.W. Goodman), Supermoney, p.286.

# Acknowledgements

First and foremost, I wish to acknowledge the contributions of my advisor and committee chairperson, Leonard Shabman, to this study and to my education. Prior to and throughout the period of time devoted to this dissertation, his candid appraisal, assistance, and encouragement have strengthened my abilities as researcher and writer. I wish to thank, also, Dan Taylor, Randy Kramer, Sandra Batie, Darrell Bosch, and Lee Daniels for serving as committee members. Each contributed uniquely and significantly to this final product. The Virginia Environmental Endowment provided partial support for this research through VEE Grant 86-29

I owe a debt of gratitude to numerous persons in the Department of Agronomy for serving as sounding boards and sources of information. I wish to thank, too, extension agents in the study area for their willing assistance.

I am grateful to everyone in the data lab who answered questions and put out fires. Todd Pukanecz, especially, spent more than a fair amount of time helping me cope with computer illiteracy. Thanks to Polly Ligon and Kurt Stephenson, Dillman disciples, for their help with the survey. Thanks to Gordon Groover for answering every silly question I came up with. Thanks to Wayne Thomas for the drawings and everything else. A special thanks to Donna Cromer for everything she did to help me and for being a good friend. Many special friends helped to make my tenure at Virginia Tech memorable, and I am grateful to them all.

Steve Koontz deserves a pat on the back (no pun intended) for putting up with me throughout the dissertation and job-hunting phases of our life together. Now, once the wedding planning phase is over, things should be pretty peachy.

Finally, this dissertation is dedicated to my parents. Their support, both financial and emotional, has enabled me to achieve this goal, and I am eternally grateful.

"Would you tell me please, which way I ought to walk from here?"
"That depends a great deal on where you want to get to," said the Cat.
"I don't much care where -" said Alice.
"Then it doesn't matter which way you walk," said the Cat.
"-as long as I get somewhere," Alice added as an explanation.
"Oh, you're sure to do that," said the Cat, "if you only walk far enough."

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# Section I

## *Introduction*

# Chapter 1

## *Introduction*

Nonpoint source pollution continues to jeopardize water quality in the Chesapeake Bay. In particular, nutrient loadings to the Bay are a source of concern for water quality agencies. Nutrients are essential to the productivity of the Bay, but excess nitrogen and phosphorus levels in the Bay and its tributaries contribute to decreased levels of dissolved oxygen (DO) and threaten aquatic vegetation and animal life. The results of water quality modeling conducted for the Environmental Protection Agency's (EPA) Chesapeake Bay Program indicated that, in an average year, nonpoint sources contribute 39 percent of the phosphorus load and 67 percent of the nitrogen load, Bay-wide. Cropland generates the largest share of the nonpoint nutrient load basin-wide, contributing 27 percent of the phosphorus and 60 percent of the nitrogen in an average year (USEPA).

### Nonpoint Pollution Control in the Chesapeake Bay Drainage

Concern over the impact of agricultural pollution on the general water quality of the Bay has resulted in the development of federal and state programs to reduce agricultural runoff into the Bay and its tributaries. Initially, water quality management activities for the Chesapeake Bay were carried out under Section 208 of the 1972 Federal Water Pollution Control Act Amendments. Under the 208 process, state-wide plans were developed to identify critical problem areas, to select suitable best management practices (BMPs) to reduce pollution, and to designate management agencies responsible for agricultural nonpoint source control planning and implementation (March et al.). In Virginia, the State Water Control Board (SWCB) is the lead state water quality management agency and, as such, has been responsible for development and implementation of nonpoint source control plans. The Division of Soil and Water Conservation (DSWC) coordinates the Chesapeake Bay Nonpoint Source Pollution Program and has been designated as the lead management agency for development and implementation of the agricultural BMP plan (DSWC).

More recent actions have modified nonpoint pollution control activities in Virginia. The 1987 amendments to the Clean Water Act mandate that states delineate those waters which will not reach the standards and goals set forth by the law without specific attention to nonpoint pollution and develop a state-wide plan to control nonpoint pollution. In turn, federal grants will be made available to states for use in carrying out their comprehensive control programs (U.S. Congress). Additionally, the recent Chesapeake Bay Agreement signed by officials in Virginia, Maryland, Pennsylvania and the District of Columbia includes the goal of reducing levels of excess nutrients, both nitrogen and phosphorus, by 40 percent by the year 2000 (Anonymous, 1988). Virginia water quality officials have recognized that, even at the most stringent levels of waste-water treatment, reductions of point sources will not meet this goal (Cox). Thus, the spotlight is on nonpoint control, and agricultural nonpoint pollution is receiving special attention.

Virginia's current agricultural nonpoint source control strategy concentrates upon encouraging voluntary implementation of BMPs by farmers through administration of educational programs and technical and financial assistance programs. Efforts to improve the agricultural nonpoint pollution control program now focus upon increasing the effectiveness of the current BMP strategy by education, targeting and monitoring (DSWC). The current BMP strategy has developed from a continuation and expansion of traditional soil conservation programming focused upon maintenance of topsoil on the farm. BMPs, traditionally structural and cultural practices, are designed to control soil erosion and runoff and the associated loss of sediment and chemicals, such as phosphorus, from cropland. However, several studies have raised questions about how effectively traditional BMPs can control the loss of nitrogen from cropland (Crowder and Young; McDowell and McGregor). Nitrates, the plant-available form of nitrogen which is dissolved in water, may be found in runoff beyond that retained by sediment control. In addition, while BMPs such as terraces, cover crops, and no-till may reduce surface flows and the loss of nitrates in runoff, studies have suggested that practices which hold water on the field may result in greater percolation and subsequent leaching of nitrates to groundwater (Knisel et al.).

## *Nitrogen Pollution Control - A Special Case*

The difficulties with preventing the loss of nitrogen from cropland once it has been applied suggest that nitrogen pollution control efforts may be better served by an input management program (Odum). Comprehensive management of the form, amount, and timing of nitrogen applied would serve to reduce the amount of residual nitrogen subject to loss by runoff or leaching from cropland (Papendick et al.). From a mass balance perspective (Legg and Meisinger), all nitrogen which is introduced into the soil-plant system must be accounted for at the end of the growing season. Residual nitrogen, that portion of applied nitrogen which is neither used by the crops to which it is supplied nor stored in the soil organic matter until the next growing season, represents a potential water quality problem. A production system which matches, as closely as possible, nitrogen availability in the soil to crop needs is more likely to reduce the amount of residual nitrogen (Papendick et al.). There are a number of management practices which will better time plant available nitrogen to plant uptake of nitrogen. For example, timing fertilizer applications to match nitrogen availability to crop needs will reduce the total nitrogen subject to loss. In addition, use of organic sources of nitrogen, including leguminous green manures and animal manures, which decay slowly to release nitrogen over the growing season would distribute the release of plant available nitrogen to more closely correspond to the timing of plant needs.

Alternative nitrogen management systems might also be of interest to farm decision makers. From a farm management perspective, nitrogen which is applied to cropland but which is neither removed by the crop nor stored in the soil for subsequent crops can represent a significant loss. Although nitrogen fertilizer is relatively inexpensive on a per unit basis, it is often a large percentage of total production costs. For example, for a Virginia corn and wheat producer, nitrogen fertilizer can represent 20 to 25 percent of total variable input costs (Perkinson). Nitrogen management systems which reduce the need for fertilizer nitrogen and reduce the loss of applied nitrogen from cropland might be economically attractive to farm decision makers.

However, there are costs associated with a transition from a conventional production system to a system incorporating alternative nitrogen management strategies, costs which, in light of the typically short planning horizons and precarious financial positions of individual producers, may present barriers to such a transition. For example, management problems and information deficiencies associated with learning a new system may result in an initial decline in profits until the adjustment period is over. Additionally, limited access to resources, for example legume seeds or livestock wastes, may increase the cost of their use as alternative sources of nitrogen. There may be other constraints to conversion, as well. A lack of information or even misinformation about alternative nitrogen sources may prevent producers from considering them as acceptable alternatives. Similarly, concerns over the riskiness of alternative systems, or even a general neophobia, may prevent a transition.

As water quality planners continue to search for nitrogen pollution control programs, one attractive option may be to provide information and incentives to overcome the barriers to farmer adoption of alternative nitrogen management strategies. However, encouraging conversion from conventional production systems to alternative systems as a water quality management strategy can involve a change in the traditional emphasis of pollution control programs on soil conserving BMPs. While education and cost sharing activities have been the primary tools used to encourage BMP adoption, the application of such programs might have a change in focus. For example, education programs would focus on providing farmers with reliable information on alternative sources of nitrogen and their incorporation into a comprehensive nitrogen management system. In the cost sharing program, the eligibility of individual practices for cost sharing would depend on their compatibility with a total farming system designed for nitrogen pollution control. In addition, a number of alternatives to cost sharing might be used to provide incentive for a transition to alternative production systems. For example, input subsidies or programs designed to increase availability of alternative nitrogen sources and tax incentives to offset the initial costs of transition may overcome barriers to the conversion from conventional to alternative nitrogen management systems.

## Objectives

To address the issues discussed above, three primary research objectives are identified.

1) The first objective of the study is to identify and evaluate alternative production systems designed to manage the amount, timing, and form of nitrogen fertilizer applications. Identification and evaluation of the systems will be based upon a) the compatibility of alternative production systems with existing row crop production in the Virginia Chesapeake Bay region; b) the on-farm net returns to production systems using alternative nitrogen management strategies; and c) the nitrogen residuals from production systems using alternative nitrogen management strategies.

2) The second major objective of the research is to identify the physical and attitudinal constraints on farmers' conversion from conventional to alternative production systems in the Virginia Chesapeake Bay region.

3) The third main objective is to describe the effectiveness of alternative policy tools for encouraging the transition to alternative systems and to identify future research needs and priorities to improve physical and economic models for use in analyzing alternative nitrogen management strategies and pollution control policies.

## Methods and Procedures

### *The Study Area*

The study area is located within the Northern Neck and Middle Peninsula regions of eastern Virginia. The Northern Neck region includes those counties which lie between the Potomac and Rappahannock Rivers. The Middle Peninsula counties lie between the Rappahannock and York Rivers. Figure 1.1 shows the location of the study area within the Chesapeake Bay drainage basin. The Northern Neck and Middle Peninsula regions lie in the tidal portion of the basin. The Potomac, Rappahannock and York rivers are brackish to saline in this tidewater region. Most of the soils in the study area, which is in the Coastal Plain region, are well drained to excessively drained sandy and sandy loam soils (Nicholson; Robinette and Hoppe).

Agriculture in this area is dominated by the production of grain crops. Corn, wheat, barley and soybeans are the primary cash crops, in terms of acreage and sales. The 11 county study area represented 22 percent of Virginia's total corn grain production in 1986, 23 percent of soybean

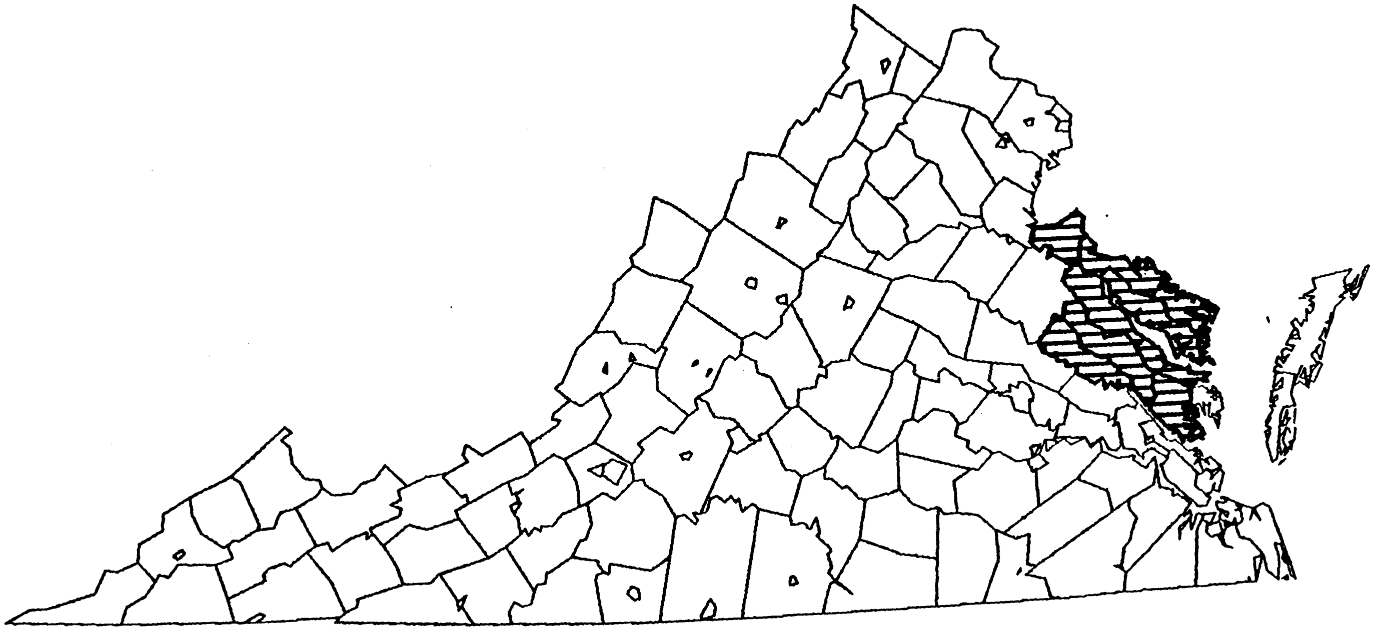

Figure 1.1. The Study Area

production, 26 percent of wheat production, and 36 percent of barley production (Viginia Agricultural Statistical Service). In addition, a few livestock, horticultural and specialty crop operations can be found (U.S. Department of Commerce).

## *Structure of the Study*

A three-part study was designed to achieve the objectives listed above. The three main components of the study included the development and empirical estimation of a physical nitrogen model, an economic optimization model, and an innovation adoption model. The results generated from using each of the analytical tools were then combined to examine the potential effectiveness of alternative policy tools for encouraging the conversion to alternative production systems.

As an initial step in the analysis, a physical model was constructed which could be used to examine nitrogen movement to and from agricultural production systems. Agronomy, soil science, and biology literature, as well as discussions with experts in these fields, were used to develop a nitrogen mass balance model which included, in particular, the intertemporal nature of the nitrogen cycle. Based on this model, nitrogen budgets were constructed to be used in the economic analysis. A mass balance model was used in this research, rather than a more sophisticated water quality model, because the water quality models do not explicitly account for either the long run buildup in soil fertility or the nitrogen carryover resulting from the use of organic nitrogen sources.

The economic analysis was conducted using an optimization model to examine producers′ choice of production system. The conventional production system in the study area was identified, as were alternative systems compatible with agriculture in the study area, through conversations with Extension personnel in the study area and Extension specialists at Virginia Tech. A multi-period linear programming (LP) model was constructed to compare the systems. The primary objective of the model was to examine the present value of net returns from the alternative systems. Nitrogen budgets for each system were incorporated into the model to examine nitrogen use and residual nitrogen levels for the systems over time.

The relative profitability of the alternative production systems provides evidence as to which system(s) is more likely to be used by producers. Economic theory asserts that a profit- maximizing producer will choose that production system which maximizes net returns over his planning horizon. However, the observation that producers make choices which do not maximize profits suggests that the economic model may inadequately portray the producer's decision analysis. Specifically, the assumptions of the underlying theory may not hold. For this reason, alternative theories have been used as a basis for examining producers' decisions. One such alternative is the theory of innovation diffusion and adoption.

The theory of innovation diffusion and adoption presents a number of factors, in addition to profitability, which may influence a producer's decision to use a particular production system. In order to consider the importance of some of these factors, an adoption model was developed. A farmer survey was conducted to collect information on farmers' adoption decisions, and a set of empirical adoption models was estimated using the survey results.

The economic and adoption models were then used to examine the potential effectiveness of alternative policy tools for encouraging the transition to alternative production systems and to determine future research needs. The farmer survey and the LP model were used to examine alternative policy tools. A sensitivity analysis was conducted for the LP model to determine the performance of alternative systems given changes in crucial parameters and to illuminate parameters which, given additional research by physical scientists, might be improved and thereby significantly change model results.

## *Organization of the Dissertation*

This dissertation is organized to reflect the three-part structure of the study. As discussed above, the research was conducted using three primary tools: the physical model, the economic model, and the adoption model. In section II of the dissertation, the basis for the physical nitrogen model is presented. The discussion in section II consists primarily of agronomic, soil science, chemical and biological information which underlies the physical mass balance model.

In section III, the economic model is presented. Chapter three develops the theoretical basis for the empirical optimization model. Economic theory of the firm provides the framework for analyzing the profitability of alternative systems and examining farmers' choice of nitrogen management system from a profit maximization perspective. The empirical model is also presented in chapter three, and the results are presented in chapter four.

Section IV presents the adoption model. In chapter five, the innovation diffusion and adoption theory is discussed as a response to recognized weaknesses and limitations in the economic theory, and an empirical adoption model is developed. In chapter six, the farmer survey which provided the data for the empirical adoption models and the analytical technique used are discussed, and results of the adoption model estimation are presented.

In section V, the results of the economic model and adoption model are discussed in terms of the policy implications for influencing farmers' decisions to adopt alternative production systems. In chapter seven, the models are used to examine the impact of alternative policy tools on the profitability of alternative systems and on farmers' adoption decisions. This chapter also includes the results of a sensitivity analysis conducted to examine future research needs.

# Section II

## *The Physical Model*

# Chapter 2

## *Nitrogen in Agriculture*

Control of nonpoint sources of nitrogen from agriculture is difficult because of the dynamic nature of nitrogen transformations and transport, and the many sources of nitrogen. Also, sustained crop production requires that nitrogen fertilizers or nitrogen-rich organic residues be added at each production period due to the many avenues of loss and the low crop recovery of nitrogen (Keeney, 1983). The purpose of this chapter is to review the biological, chemical and physical processes affecting the transport of nitrogen to and from cropland and to discuss management approaches to minimize nonpoint discharges of nitrogen.

Previous economic studies have not adequately accounted for the complexity of the nitrogen cycle and the fate of nitrogen in agricultural systems. Generally, single period economic analyses have neglected the carryover and buildup of organic nitrogen in crop production systems using organic nitrogen sources (Crowder and Young; Goldstein and Young). Multi-period studies conducted have provided a longer horizon for decision analysis but, nevertheless, have not incorporated organic nitrogen carryover into the analysis (Dabbert and Madden; Helmers, Langemeier and Atwood; Walker). This neglect has been due, in part, to the relative uncertainty associated with the parameters in a nitrogen cycle model. Because of its dynamic nature, the nitrogen cycle is a complex phenomenon. However, substantial information exists in the literature which can provide a basis for constructing a model of the nitrogen cycle and incorporating such a model into an economic analysis of alternative nitrogen management systems.

## The Nitrogen Cycle in Agricultural Soils

The availability of nitrogen for crop growth and for loss to surface and ground water results from a complicated series of chemical and biological reactions referred to as the nitrogen cycle. Figure 2.1 presents a diagrammatic description of this cycle. The key biological transformations of nitrogen are: (1) immobilization, the assimilation of inorganic forms of nitrogen ($NH_4$, $NO_3$) by plants and microorganisms to form organic nitrogen compounds; (2) ammonification or mineralization, the decomposition of organic nitrogen to ammonia ($NH_3$) and then ammonium ($NH_4$); (3) nitrification, the microbial oxidation of $NH_4$ to nitrites ($NO_2$) and then nitrates ($NO_3$); (4) denitrification, the reduction of $NO_3$ to nitrous oxides ($N_2O$) or elemental nitrogen ($N_2$); and (5) nitrogen fixation, the reduction of $N_2$ to $NH_3$ (Keeney, 1983).

### *Immobilization and Mineralization*

The opposing processes of immobilization and mineralization occur continuously and simultaneously in most systems where organic debris are undergoing microbiological decomposition. As long as conditions are favorable for biological activity, inorganic nitrogen is continuously transformed to organic and organic to inorganic nitrogen, although the rate of turnover may be low (Bartholomew). Net mineralization (inorganic nitrogen released in excess of that immobilized) often is about two to four percent of the total soil nitrogen per year in temperate zone soils. While accurate prediction of the amount of nitrogen released is difficult, the nitrogen mineralized in some agricultural soils can provide a significant portion of total crop needs (Keeney, 1983).

The net amount of nitrogen mineralized or immobilized in a given time is a function of many factors including soil type, temperature, water and aeration. When organic materials are added to the soil, these materials serve as energy and nutrient sources for the metabolism and growth of microbial organisms (Keeney, 1983). Under suitable conditions, rapid increases in the microbial population will occur, placing a high demand on inorganic nitrogen for use in cell synthesis. If the organic material is carbonaceous (a high carbon (C) to nitrogen (N) ratio), more energy is available for growth than nitrogen for synthesis, resulting in a net immobilization for an extended period of

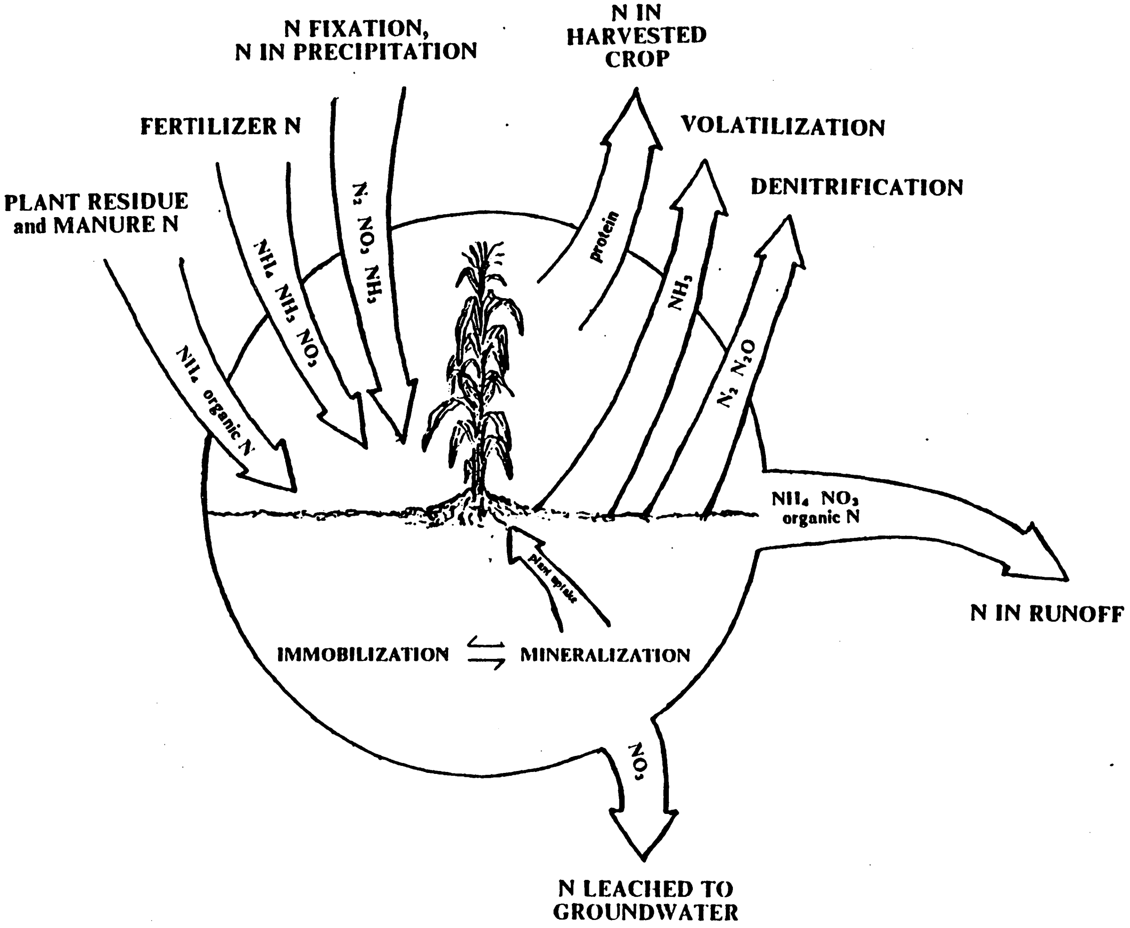

Figure 2.1. The Nitrogen Cycle in Agricultural Soils

time. If it is proteinaceous (a low C to N ratio), inorganic nitrogen may be liberated early in the decomposition phase. In general, residues with a C to N ratio of 22 or below, corresponding to a total nitrogen content of about two percent, are associated with rapid net mineralization, while higher C to N ratios are associated with net immobilization (Bartholomew).

Ammonium, the product of mineralization, is adsorbed to soil and, as a result, is not subject to leaching (Valiulis). This increases the availability of this inorganic nitrogen form for plant growth. Higher plants are able to use this form of nitrogen, often very readily. Young plants of almost all kinds are especially capable in this respect, although they seem to grow better if some $NO_3$ is also available (Brady). Although plants can use nitrogen in the $NH_4$ form, much of it will be transformed to the leachable $NO_3$ form before it is used by plants (Valiulis).

### *Nitrification*

Nitrification is a key reaction in the nitrogen cycle. It transforms the relatively immobile $NH_4$ into $NO_3$, which can be readily taken up by plants, leached to groundwater, or denitrified (Keeney, 1983). Under ideal temperature, soil, and moisture conditions, nitrification occurs at a very rapid rate (Brady). When temperatures rise above 50 degrees farenheit in well aerated and properly limed soils, the nitrification process begins, and complete conversion of $NH_4$ to $NO_3$ can be expected during the warm months (Valiulis).

### *Denitrification*

Denitrification is the process by which $NO_3$ is converted back into $N_2$ and $N_2O$, which then escape into the air. Under the right conditions, denitrification can represent a major source of nitrogen loss. The process occurs quickly in poorly aerated, very moist, or water logged soils. In addition to the anaerobic environment, organic matter is essential for the denitrifying bacteria, which obtain their oxygen from the oxygen contained in $NO_3$ (Keeney, 1983).

Denitrification losses fall into two categories - losses that are rapid and extensive, and those involving continuing small loss of nitrogen over an extended period of time (Broadbent and Clark).

The former occur especially when soils containing $NO_3$ and readily decomposable organic matter are exposed simultaneously to warm temperatures and excessive wetness. If water stands on the soil for only two or three days during the growing season, most of the $NO_3$ will be lost (Valiulis). The continuing small losses of nitrogen which occur over the course of the growing season are more substantial, in terms of total denitrification losses. This pathway may remove 10 to 15 percent of the total yearly mineral nitrogen input (Broadbent and Clark).

### *Nitrogen Fixation*

Biological nitrogen fixation refers, primarily, to the symbiotic relationship in legumes in which legume nodule organisms (Rhizobium bacteria) transform $N_2$ into a useable form. How the plant absorbs this nitrogen after it has been secured by the bacteria is not well understood (Brady). However, the effectively nodulated legume, growing vigorously, can provide itself through the fixation of $N_2$ with all the nitrogen it needs, even when none is available from the soil (Nutman).

After the legume dies, the fixed nitrogen becomes available to other plants by the normal process of mineralization. There is also evidence that, under some conditions, the living legume root may excrete appreciable amounts of nitrogen (Nutman). The amount of nitrogen fixed by individual legumes depends on soil conditions, principally aeration, drainage, moisture, pH, and the amount of available calcium. Even when these conditions are favorable, however, a large amount of readily available nitrogen in the soil will inhibit the nodule bacteria and thereby reduce fixation (Brady).

## Managing Soil Nitrogen in Agriculture: A Mass Balance Perspective

Nitrogen balances have been a valuable tool in expanding knowledge of the nitrogen cycle. They have contributed by identifying mechanisms of nitrogen transfer and indicating the size of various nitrogen reservoirs. Their main use has been in estimating the net nitrogen loss, or the unaccounted for nitrogen, in a given agricultural production system (Legg and Meisinger). The nitrogen balance approach is also referred to as the mass balance approach (Hauck and Tanji).

This approach is valuable for an economic analysis of nitrogen management because it explicitly accounts for all inputs and losses of nitrogen to and from a production system. In addition, this approach accounts for the storage of nitrogen. Thus, the allocation of nitrogen inputs over time can be examined, as well as the change in nitrogen residuals, as inputs are varied.

### *The Mass Balance Concept*

The mass balance concept is a derivative of the basic law of physics governing the conservation of matter. More commonly referred to as materials balance in economics literature, this principle recognizes that all inputs into a system, whether an economic system or a physical production system, must be represented by outputs from that system (Freeman, Haveman and Kneese). An important result of the application of the materials balance model in the environmental economics field is the recognition of residuals as one of the outputs. In general, residuals are the by-products of productive activity, "discommodities" which dissipate into the environment or which must be disposed of (Randall).

As applied to nitrogen balances, the mass balance principle emphasizes that nitrogen is conserved in the various transformations and biological processes of the soil-plant production system (Legg and Meisinger). That is, any nitrogen inputs into the system must be accounted for in outputs or as residuals from that system. Figure 2.2 presents a mass-balance model of the transport of available nitrogen in agricultural soils.

### *Nitrogen Sources in Agricultural Soils*

As shown in figure 2.2, there are three general sources of nitrogen in a crop production system. A basic source of nitrogen for crops is the mineralization of nitrogen as organic matter in the soil decomposes. Soil organic matter generally contains about five percent nitrogen (Brady). Thus, for example, a three percent organic matter soil (assuming a typical soil with a seven inch plow layer weighing 2,000,000 pounds) would contain about 3000 pounds of nitrogen per acre. As noted previously, net mineralization is generally about two to four percent of total soil nitrogen in a av-

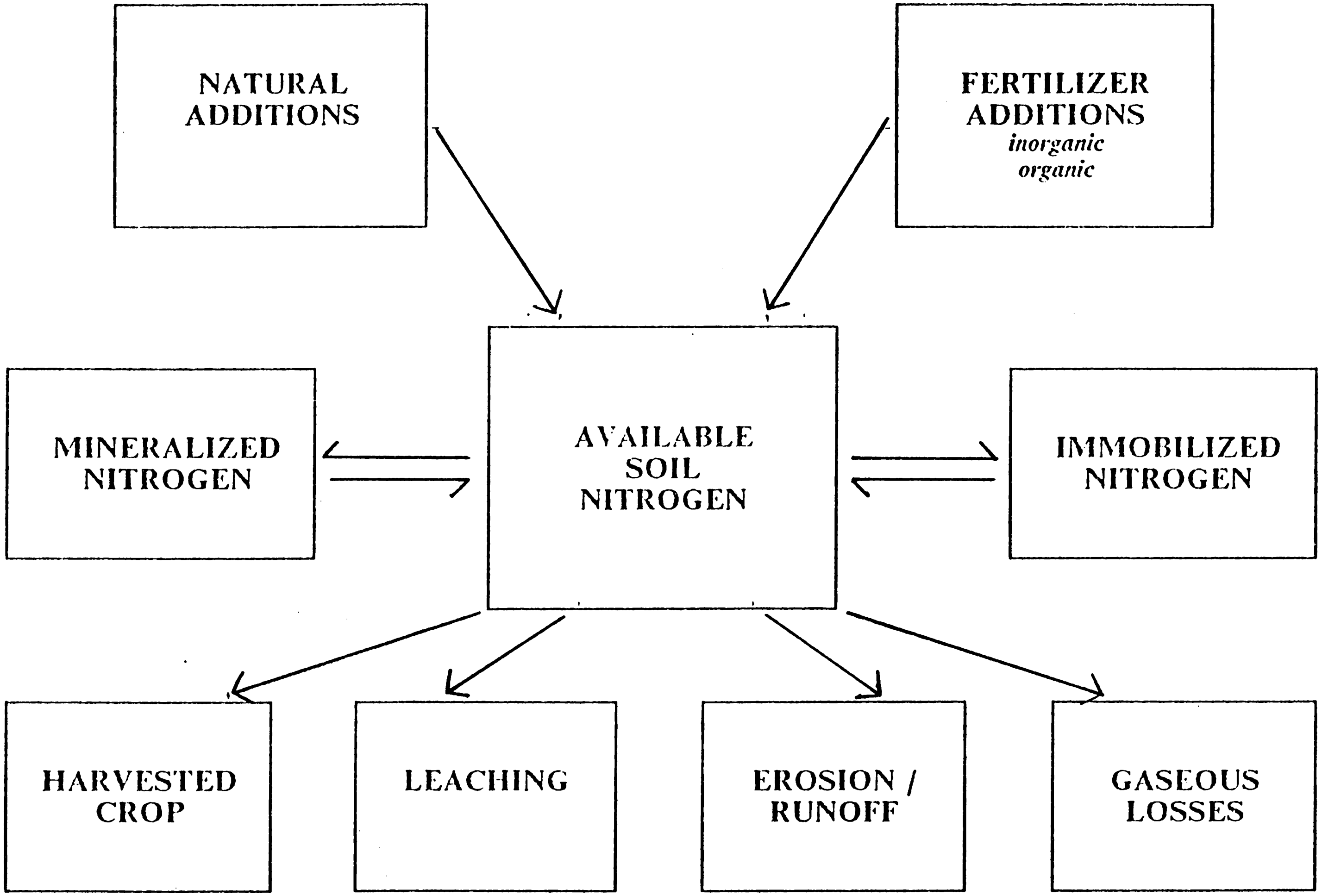

**Figure 2.2. Single-period Mass Balance Model of Nitrogen Transport in Agricultural Soils**

erage year. Therefore, a typical three percent organic matter soil would supply approximately 90 pounds of nitrate nitrogen per acre during a normal growing season (Ankerman and Large).

In addition to the decomposition of soil organic matter, the decomposition of crop residues, if the C to N ratio of the residues is sufficiently low, may supply nitrogen to crops. The nitrogen not mineralized in the first season becomes part of the soil organic matter and will decompose slowly over a period of many years (Bartholomew).

A second source of nitrogen for crop growth, and the most significant source, is the addition of nitrogen fertilizers. Both organic and inorganic forms of nitrogen are used as fertilizers, with the latter by far the largest portion of fertilizer additions in the Chesapeake Bay region of Virginia. Liquid and granular forms of $NO_3$ and $NH_4$ compounds are the most common inorganic nitrogen fertilizers supplied to crops (Donahue and Hawkins).

Organic nitrogen fertilizer sources include crop residues used as green manures, livestock manures, and other organic materials such as sewage sludge. Nitrogen-fixing legume crops are generally used as green manures because they add both nitrogen and organic matter to the soil, while non-legumes add organic matter only (Pieters and McKee). The nitrogen availability from a particular legume green manure depends upon the nitrogen content of the crop, the amount of top growth or residue incorporated into the soil, and the rate of decomposition of the residue and release of nitrogen. For example, a 1.5 ton application of a legume green manure containing 75 pounds of nitrogen may release 45 pounds during the early stages of decomposition in the first season (Bartholomew). The 35 pounds of nitrogen remaining with the residues would be distributed in a regularly decreasing manner during the next few years (Lohnis). Three to 10 percent of the residue nitrogen may be recovered during the second cropping season after application (Fribourg and Bartholomew; Bartholomew; Lohnis). It is not clear that all of the nitrogen will be recovered (Lohnis), and the amounts mineralized in subsequent years are likely to be too small to measure with field plot techniques. However, continued treatments with green manures have cumulative effects which often are measurable in the second and third season after turning under the residue (Bartholomew).

Livestock manures are another source of nitrogen for crops. Manures, unlike legume residues, have a readily available, inorganic nitrogen fraction as well as an organic nitrogen fraction. The inorganic fraction, usually 30-45 percent of the total nitrogen content depending upon type of livestock species and form of manure, is highly volatile, although immediate soil incorporation of manures will significantly reduce the loss of inorganic nitrogen through volatilization (Givens). The organic fraction, as with green manures, releases plant available nitrogen as it decomposes. Approximately 50 percent of the organic fraction becomes available during the first growing season and the remainder becomes available over the next few years (Givens). Again, it is not clear that all of the organic nitrogen is ever released. The decay constants presented in table 2.1 account for the plant availability of nitrogen from the total amount of nitrogen in the manure, both inorganic and organic, from various livestock species. These decay rates will be affected by the climate and soil conditions under which the decay process occurs, including temperature and moisture.

Sewage sludges are another source of organic nitrogen fertilizer. Application rates of sludge are usually limited by the amount of nitrogen needed for crop growth; however, in some cases, the quantities of lime or phosphorus in the sludge may limit application rates. Nitrogen in sludge is present in the $NH_4$ and organic forms. To prevent volatilization of the inorganic nitrogen, incorporation of the sludge is generally recommended (Simpson et al.).

As with other organic forms of nitrogen, the organic nitrogen in sludge becomes available over a period of years. For sludge, the proportion of organic nitrogen that mineralizes is affected by the stabilization process used by the sewage treatment plant. Table 2.2 presents mineralization rates for various types of sludge. After three years, four percent or less of the original organic nitrogen will be mineralized during the growing season (Simpson et al.).

A third source of nitrogen to crop production systems is through natural additions. There are many avenues for the natural addition of nitrogen. The most significant natural source of nitrogen is the biological fixation of $N_2$ by legume crops. As discussed previously, a vigorously growing legume crop can supply all of the nitrogen it requires.

**Table 2.1. Decay Constants Used to Estimate Animal Manure Nitrogen Availability to Crops, Considering Entire Cropping Year for Degradation of Manure**

| | Nitrogen in Manure | Decay Constant for Year After Application | | | |
|---|---|---|---|---|---|
| Manure Source | (% of dry weight) | 1 | 2 | 3 | 4 |
| Poultry (broilers, turkeys) | 3.8 | .75 | .05 | .05 | .05 |
| Swine | 2.8 | .90 | .04 | .02 | .02 |
| Dairy, fresh | 3.5 | .50 | .15 | .05 | .05 |
| Dairy, anaerobic | 2.0 | .30 | .08 | .07 | .05 |
| Beef feeders, fresh | 3.5 | .50 | .15 | .10 | .05 |
| Beef feeders, dry corral | 2.5 | .40 | .25 | .06 | .03 |
| | 1.5 | .35 | .15 | .10 | .05 |
| | 1.0 | .20 | .10 | .05 | .05 |

Source: Gilbertson et al.

**Table 2.2. Estimated Nitrogen Mineralization Rates for Sewage Sludges**

| Sludge Type | Years After Application 1 | 2 | 3 |
|---|---|---|---|
| Lime stabilized, Raw, or Waste activated | .45 | .22 | .11 |
| Aerobic digestion | .35 | .17 | .08 |
| Anaerobic digestion | .25 | .12 | .06 |
| Composted | .15 | .08 | .04 |

Source: Simpson et al.

Table 2.3 presents some average amounts of nitrogen fixed by various legumes. After harvest, the legume crop residues which remain behind will supply nitrogen for subsequent crops as they decompose.

Other natural additions of nitrogen include nitrogen fixation by non-legumes, precipitation, direct $NH_3$ adsorption, and particulates such as dust, pollen and animal droppings (Fried, Tanji and Van De Pol). The total nitrogen input of these natural additions is usually quite low, especially compared to biological fixation and organic and inorganic fertilizers.

### *Nitrogen Losses From Agricultural Soils*

As shown in figure 2.2, nitrogen inputs to the crop production system leave the system by one of four primary channels. First, a major loss of nitrogen from cropland is in harvested crops. The nitrogen content of the harvested product can be measured quite accurately, and in fact, good estimates can be made from the relationship of yield to nitrogen content for almost any crop (Fried, Tanji and Van De Pol). Over a typical range of crop yields, a linear relationship between crop yield and nitrogen content can be assumed (Brann). Those crops for which only grain or plant tops are

**Table 2.3. Reported Quantities of Nitrogen Fixed by Various Legume Species**

| Species | Nitrogen Fixed (lbs/ac/yr) |
|---|---|
| Alfalfa | 102-199 |
| Alfalfa-orchardgrass | 13-121 |
| Clarke clover | 19 |
| Birdsfoot trefoil | 44-100 |
| Chickpea | 21-75 |
| Common bean | 2-108 |
| Crimson clover | 57 |
| Faba bean | 159-224 |
| Field peas | 155-175 |
| Hairy vetch | 99 |
| Ladino clover | 146-168 |
| Lentil | 149-169 |
| Red clover | 61-101 |
| Soybean | 20-277 |
| Subterranean clover | 52-163 |
| Sweet clover | 4 |
| White clover | 114 |

Source: Power

removed from the field will remove less total nitrogen than silage and hay crops which leave behind very little residue.

Leaching is the second and often the most important channel of nitrogen loss from fields after that accounted for in plant uptake. Losses occur mainly as $NO_3$, the movement of which is closely related to water movement (Allison, 1973). Major losses of nitrogen occur when soil $NO_3$ content is high and water movement is large. On agricultural land, tillage stimulates the ammonification of organic nitrogen and subsequent nitrification, leaves the soil bare for a period of time, and sets the stage for possible $NO_3$ loss (Legg and Meisinger).

Leaching losses are also strongly affected by seasonal effects, such as precipitation and temperature. In humid, temperate regions, mineralization rates are low in winter, but leaching of residual $NO_3$ from the previous season often occurs. In the spring, $NO_3$ accumulates as nitrification rates increase and nitrogen fertilizers are applied. If heavy rains occur before spring-planted crops are growing vigorously, large amounts of $NO_3$ can be leached below the root zone (Legg and Meisinger). Nitrate leaching is least likely to occur during the summer, when evapotranspiration usually exceeds precipitation and plant uptake rates are high (Allison, 1973).

A third channel of nitrogen loss is wind and water erosion which may, in ordinary cropping systems where proper control measures are not used, remove nearly as much nitrogen as is removed in the harvested crop (Allison, 1965). Most of the nitrogen lost by soil erosion is in organic forms (Legg and Meisinger). The loss of organic nitrogen does not represent a loss of readily available nitrogen; however, it is a large loss of potentially available nitrogen that will eventually be deposited in streams, lakes and oceans with very little opportunity to be recycled into agricultural systems (Legg and Meisinger).

Surface runoff will also contain soluble nitrogen, primarily $NH_4$ and $NO_3$. Inorganic nitrogen concentrations and export are the net result of numerous factors, including precipitation, soil moisture prior to rainfall events, ground cover, and conservation practices such as terraces (Keeney 1983; Legg and Meisinger). Runoff losses of nitrogen are generally low, except when high rates of nitrogen fertilizer are applied just before high levels of rainfall. In most cases, total nitrogen losses associated with sediment are several times greater than soluble nitrogen losses in runoff (Legg and Meisinger).

Gaseous losses are the fourth major channel of nitrogen from agricultural soils. Denitrification losses occur when soils contain large quantities of $NO_3$ and are deficient in oxygen (Allison, 1965). As discussed previously, most nitrogen loss by denitrification results from a series of small losses over the course of the growing season during short periods of excessive rainfall. In fine textured soils such losses may be large; however, in sandy soils, such as those in eastern Virginia, denitrification loss is negligible (Allison, 1965).

Volatilization of ammonia is another gaseous loss of nitrogen, although it is usually small. Under conditions where animal manures and other readily decomposable organic materials are allowed to decompose on the soil surface, it is possible for ammonia to escape (Allison, 1965). Similarly, broadcasting inorganic fertilizers on the soil surface without incorporation will enhance volatilization (Legg and Meisinger). However, nitrogen loss is small if the ammonia source is incorporated into the soil (Allison, 1965).

Figure 2.2 presents a fifth outlet of nitrogen inputs into a crop production system - immobilization. Unlike the other outlets, however, immobilized nitrogen is not lost from the agricultural system. Inorganic nitrogen immobilized in the soil organic matter may come from inorganic nitrogen fertilizers and from nitrogen mineralized from decomposing crop residues or manures. As discussed previously, most of the immobilized nitrogen will eventually be released as organic matter decomposes. However, some of the immobilized nitrogen will remain in the organic form and become an integral part of the soil organic matter. In this form, the nitrogen is mineralized only very slowly, if at all (Brady).

When inorganic fertilizer nitrogen is added to soil, a significant fraction may be immobilized during the first growing season, perhaps as much as 20 to 35 percent (Keeney, 1986). No more than 15 percent of the nitrogen immobilized is mineralized the following year, and generally the amount mineralized is closer to five percent (Keeney, 1986; Bartholomew). Nitrogen availability from the immobilized nitrogen will decline over time, until the availability of the fertilizer nitrogen is indistinguishable from the nitrogen from soil organic matter (Stevenson and He).

From a mass balance perspective, nitrogen outputs from a crop production system in a given production period can be divided into three categories: 1) nitrogen removed in the harvested crop, 2) residual nitrogen, and 3) crop residue nitrogen and other immobilized nitrogen which is not lost from the system but rather is stored until succeeding periods. Over time, the stored organic nitrogen is converted to the inorganic form through the mineralization process. The decay rate of the organic matter depends upon the C to N ratio of the organic nitrogen source. The stock of organic nitrogen in the soil will increase as additional organic matter is introduced into the system, and the mineralization process will release increasing amounts of inorganic nitrogen. The inorganic nitrogen released leaves the crop production system through the harvested crop or as residual nitrogen or it is immobilized and stored until future periods when it will eventually be lost by one of these two avenues.

Residual nitrogen is that nitrogen lost from cropland by leaching, erosion and runoff, and denitrification.[1] The goal of water quality management programs is to reduce this residual nitrogen lost from cropland. Similarly, farm managers should be interested in minimizing the amount of nitrogen lost as residuals. There are many management practices which can be used to minimize residual nitrogen while providing adequate amounts of nitrogen for crop growth. In particular, management practices which control the amount of nitrogen applied, the timing of nitrogen applications, and the form in which nitrogen is applied can be used to minimize residual nitrogen.

## *Nitrogen Management to Reduce Residual Nitrogen*

A comprehensive nitrogen management system which matches, as closely as possible, the availability of inorganic nitrogen to plant needs will minimize residual nitrogen. Specifically, minimizing the stock of nitrates in the system at any given time will minimize leaching losses. Controlling erosion and runoff will minimize surface losses. Incorporating organic matter, such as

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[1] Soil scientists typically refer to the nitrogen which is immobilized or otherwise stored until subsequent production periods as residual nitrogen, where residual refers to *that nitrogen which remains in place* (Onken et al.; Carter et al.). However, in accordance with the mass balance model developed in environmental economics literature, residual is used here to mean the output from the system which is a *by-product* or *waste product,* while nitrogen carry-over to subsequent periods remains a potentially useful resource.

manures and sludges, will minimize volatilization losses. Thus, a production system which includes erosion control practices and soil incorporation of manures will reduce surface losses of nitrogen. However, careful planning of the amount, timing and form of nitrogen applied is also necessary to match, as closely as possible, inorganic nitrogen availability to crop uptake of nitrogen and to minimize nitrogen residuals.

**Amount of nitrogen** - There are several reasons why farmers may supply more inorganic nitrogen than is needed by crops. One reason is that farmers may overestimate the yield potential or productivity of their soils and, when fertilizing for that yield, over-apply nitrogen (Papendick et al.). The fact that some other physical factor is actually limiting yields means that the added nitrogen will not result in higher yields and the excess nitrogen will ultimately be lost.

Another problem which may influence the over-application of nitrogen fertilizer is the fact that there is not a reliable soil test for nitrogen (Hallberg). In most cases, nitrogen recommendations are based on the amount of organic matter in the soil and the crop yield history of the field. As such, nitrogen recommendations can vary widely. In a Rodale Press survey (DeVault), university and commercial soil testing labs made nitrogen recommendations which varied from zero to 230 pounds per acre of nitrogen for the same soil.

Yet another reason, and perhaps the most important, for excessive nitrogen use is the low rate of uptake by plants of the inorganic nitrogen supplied. Common figures cited in the literature suggest that, on average, only 50 percent of inorganic nitrogen applied in fertilizer is actually taken up by crops (Keeney, 1982). Of the nitrogen not accounted for in the crop, leaching, denitrification and immobilization are the primary outlets. It is not unusual for environmentally concerned individuals to voice concern over farmers' excessive use of nitrogen. The consensus among these individuals is that if farmers used less nitrogen, then nitrogen pollution would be reduced and, if farmers are using more nitrogen than crops will take up, then nitrogen fertilizer can be reduced without jeopardizing crop yields.

In reality, however, farmers' application rates for nitrogen fertilizer reflect the uncertainties associated with climate, rainfall, management, and crop rotations and their impact on the availability of nitrogen for crop growth. If, on average, 50 percent of fertilizer nitrogen is leached, lost as gas, or immobilized, then farmers must provide to their crops enough nitrogen to compensate for this loss and assure an adequate supply of nitrogen for crop growth. If a farmer supplies 50 percent more nitrogen than crops will use, it does not mean that a 50 percent reduction in nitrogen can be made without jeopardizing yields.

In a low-rainfall year, losses of nitrogen may be much lower than 50 percent, so that more nitrogen is left at the end of the season as a potential pollutant. On the other hand, if heavy spring rains fall shortly after nitrogen is applied, a large percentage of the nitrogen may be lost in runoff, may be leached, or may be lost by denitrification before plants are able to remove it from the soil. The protection against yield loss in the face of such uncertainties is reflected in nitrogen application rates for crops.

To a certain extent, the losses to leaching and denitrification may be viewed as a timing problem. Over- application of nitrogen to reduce such losses may be prevented if, through careful timing of fertilizer applications, plants remove a greater proportion of the nitrogen applied.

**Timing of Nitrogen -** Interest has increased in splitting applications of inorganic nitrogen fertilizers in order to minimize the losses of nitrogen to leaching and denitrification. Applying fertilizers near the time of maximum vegetative growth or making several applications to match crop needs can increase the proportion of applied nitrogen which is taken up by the crop.

Figures 2.3 and 2.4 show the nitrogen uptake rates for corn and wheat. The largest rate of uptake for corn does not start until approximately 30 days after emergence of the plants (Martin et al.). For wheat, maximum uptake does not begin until late February to early March (Alley et al.). Applying a small amount of nitrogen to aid germination and make nitrogen available to the young seedlings and then side- or top-dressing with the bulk of the nitrogen at the time the crop will use the most will provide a better distribution of nitrogen in the soil than a single application. This avoids the accumulation of nitrates in the soil which may be subject to leaching or denitrification before plants remove it. The application rate of inorganic nitrogen can be reduced since a greater proportion of applied nitrogen is used by the crop. Because nitrogen in supplied in accordance with crop requirements, crop yields will be maintained despite lower application rates of inorganic nitrogen fertilizer.

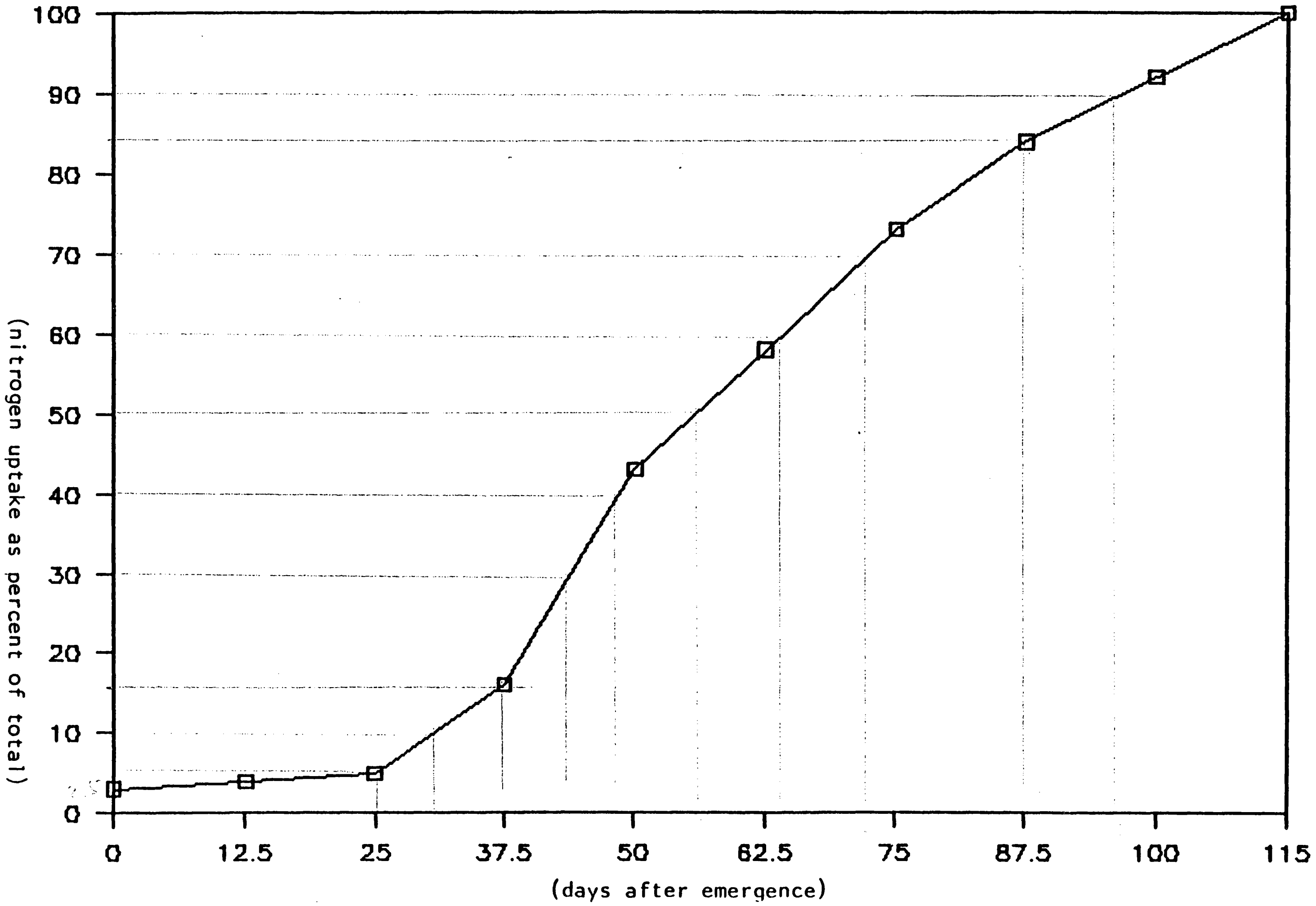

Figure 2.3. Nitrogen Uptake By Corn (Source: Martin et al.)

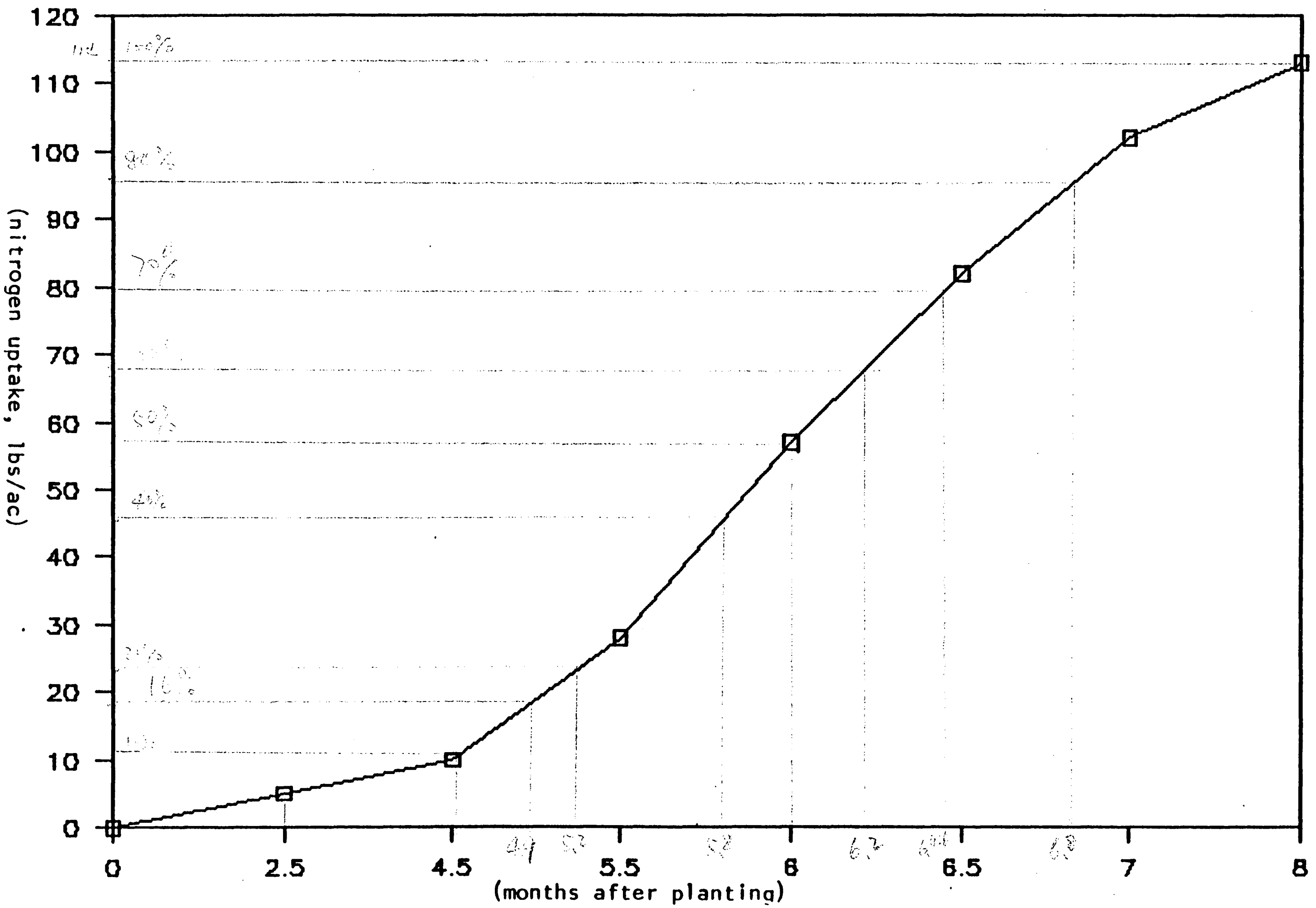

Figure 2.4. Nitrogen Uptake By Winter Wheat (Source: Alley et al.)

In addition to split applications of inorganic nitrogen fertilizer to distribute nitrogen in the soil over the growth period of the plant, there has been some interest in controlled release fertilizers and nitrification inhibitors as a means of matching nitrogen availability with plant requirements. Controlled release fertilizers, such as sulfur-coated urea, have been the subject of considerable research, and they have been found to reduce $NO_3$ leaching (Papendick et al.). However, there has been some difficulty assuring that nitrogen becomes available according to the plants needs.

Nitrification inhibitors reduce the rate at which ammonium fertilizers are nitrified. Slowing nitrification may provide a better distribution of available nitrogen during the crop growth period than slow-release fertilizers. The inhibitors are particularly effective for reducing leaching losses in areas with sandy soils and heavy rainfall during the growing season. However, the costs and inconvenience of handling the materials and mixing with fertilizers has limited the use of these products (Papendick et al.).

While both of these products may enable a reduction in total nitrogen use without reducing crop yields, any nitrogen remaining in the soil after harvest will continue to be released and may be leached over the winter. Thus, in addition to timing the application or release of inorganic nitrogen fertilizers, organic sources of nitrogen may be valuable for reducing the amount of nitrogen available for leaching.

**Form of Nitrogen** - Organic sources of nitrogen, including green manures, animal manures and sewage sludges, applied at rates consistent with crop requirements may distribute the release of plant available nitrogen so that plant uptake of nitrogen is maximized. Crop yields will be maintained if the organic matter decays at a sufficient rate throughout the crop growth period. In general, test plots have shown that organic sources provide sufficient inorganic nitrogen to satisfy a large part of crop needs (Hargrove; Klausner and Bouldin; Voss and Shrader). Organic nitrogen sources can be supplemented with inorganic nitrogen, if necessary, to meet crop needs. Additional inorganic nitrogen may also be needed if a legume stand is poor, if manures or sludges are not incorporated and significant volatilization occurs, or to assure an adequate initial supply of inorganic nitrogen at seed germination.

Legumes grown as green manures can provide substantial amounts of nitrogen to subsequent crops. In general, it is recommended that legume green manures be turned under approximately two to three weeks before the next crop is planted to allow the decay process and nitrogen mineralization to progress sufficiently (Pieters and McKee). The nitrogen becomes available slowly as the organic matter is decomposed and nitrogen is released. This should reduce the buildup of available nitrogen in the soil, especially if the crop is able to use the nitrogen as it is released (Papendick et al.).

Manures and sludges, similarly, should distribute nitrogen availability more evenly over time, although these sources of nitrogen have an inorganic as well as organic portion of nitrogen. Thus, a larger amount of nitrogen will be available at the time of application. Also, it is recommended that these sources of nitrogen be incorporated in the soil to prevent excessive volatilization of the inorganic nitrogen and runoff of nitrogen from the soil surface.

With proper management, the return of organic materials to the soil will increase the amount of active soil organic matter and improve the physical structure of the soil (Papendick et al.). Increased use of organic soil amendments will increase the amount of nitrogen mineralized from the soil organic matter and increase the tilth, water holding capacity, and aeration of the soil.

The danger of over-winter leaching of $NO_3$ is eliminated when only organic nitrogen remains in the soil over winter. When soil temperatures drop below 40 degrees farenheit, mineralization and nitrification cease (Brady). Organic nitrogen is stored in the soil until spring, at which time soil temperature rises, mineralization and nitrification resume, and inorganic nitrogen is made available for the planted crop. Immediately upon mineralization, residues release $NH_4$, which plants will use readily in early stages of growth. This further reduces the accumulation of $NO_3$ in the soil.

Finally, the use of winter cover crops as a sink for nitrogen left in the soil after harvest is another way to prevent leaching losses of nitrogen (Harmsen and Kolenbrander). When the cover crop is returned to the soil, the nitrogen is available from decomposition of the residue, and the organic material increases the active organic matter in the soil. There may be, in some areas, a danger of winter cover crops competing with cash crops for soil moisture (Power). However, in regions with adequate rainfall in the late fall and early spring, the cover crop will further inhibit nitrogen leaching by extracting water which would otherwise move freely through the soil profile, carrying with it $NO_3$ (Papendick et al.)

## Summary

The nitrogen cycle is a dynamic and complex process. However, a mass balance model of nitrogen movement within a crop production system simplifies the system to one of net inputs and outputs of nitrogen. The accounting of nitrogen used by crops, residual nitrogen, and stored organic nitrogen provides a physical basis for analyzing alternative nitrogen management strategies. Careful management of the amount, timing and form of applied nitrogen can be expected to minimize residual nitrogen losses and to make the best use of stored nitrogen reserves. However, the decision to use an alternative nitrogen management system may represent a substantial change in production operations for an individual producer. An alternative nitrogen management system may involve substitutions of inputs, adoption of alternative technologies, and a learning process and adaptation of the alternative system.

# Section III

## *The Economic Model*

# Chapter 3

## *Farm Level Nitrogen Management Decisions: Theory and Applications*

Nitrogen management involves decisions on how much nitrogen fertilizer to apply, when to apply nitrogen, and in what form to apply nitrogen. In this chapter, the theoretical basis for farm level nitrogen management decisions is reviewed. Then, an empirical model is developed to examine the nitrogen management decisions of a typical producer.

### Input Use Decisions and Profit Maximization - A Review of Theory

In general, an individual producer chooses, according to his production function, a level and combination of inputs to produce a specific level of output. The input combinations and output level chosen depend primarily upon the objective of the producer and the production constraints faced. Alternative nitrogen management strategies represent not only alternative input combinations but also alternative production technologies. When amount, timing and form of nitrogen fertilizers are changed, alternative production functions become relevant. The decision to convert to an alternative production system is based on the relative performance of the conventional system and the alternatives according to some objective function. Farm level decisions of this nature depend, according to economic theory, on the relative profitability of the alternatives.

Theory of the firm maintains that the objective of the firm is to maximize profits, given a technologically determined production function and a given set of input and output prices. For the profit-maximizing grain producer, the use of nitrogen as a production input depends upon the crop requirements for nitrogen, as specified by the production function, and the relative prices of nitrogen, other inputs, and the crop produced.

This profit maximization framework is based on four specific assumptions. First, the theory assumes that profit maximization is the only goal of the producer. The producer does not have a preference for any particular crop, input choice, or method of production, the use of which might result in an acceptable reduction in profit. Second, the profit-maximizing producer has access to perfect information regarding technology choices and current and future prices. In addition, information is costless; there is no constraint to gaining additional information on prices or technologies, and there is no learning process involved with the adoption of a new technology.

A third assumption is that the producer is risk neutral. The relative riskiness (or perceived riskiness) of alternative production technologies does not influence the profit-maximizing decision. Finally, a perfectly price elastic supply of inputs is assumed. That is, the producer can purchase all that he requires of any input, for example nitrogen fertilizer, and the price of that input is not influenced by his demand for it.

Within the profit maximization framework, given these basic assumptions, alternative strategies for managing the amount, timing and form of nitrogen applications can be examined. For each system, the profit-maximizing combination of inputs varies according to the relevant production technology. In the following discussion, the profit maximization criteria are developed for conventional and alternative nitrogen management systems. For each system, output is a composite of several grain crops: corn, wheat, barley, and soybeans. The proportion of output represented by each crop may differ across systems. The producer is a price taker; the prices of the individual crops and production inputs are fixed and do not change across systems.

### *The Conventional Production System*

Consider a profit-maximizing producer with a single output and two variable inputs - purchased inorganic nitrogen fertilizer ($N$) and all other inputs ($I$). The production function of the producer can be expressed as

$$q = f(N, I). \qquad [3.1]$$

For a given set of input prices, $P_N$ and $P_I$, the profit-maximizing combination of inputs can be shown by the point at which

$$\frac{\mathrm{MP}_N}{\mathrm{MP}_I} = \frac{P_N}{P_I} \qquad [3.2]$$

or

$$RTS_{I,N} = \frac{P_N}{P_I} \qquad [3.3]$$

where $RTS_{I,N}$ is the rate of technical substitution of all other inputs for inorganic nitrogen fertilizer. That is, $RTS_{I,N}$ is the amount of $I$ which must be substituted for each unit of $N$ in order to maintain a constant level of output.

Additionally, at the profit-maximizing input combination,

$$VMP_N = P_N \qquad [3.4]$$

and

$$VMP_I = P_I. \qquad [3.5]$$

That is, an additional unit of $N$ ($\bar{I}$) will add to total profits an amount exactly equal to the unit cost of $N$ ($\bar{I}$).

Assume, however, that the producer faces the task of reducing the amount of residual nitrogen from his crop production system. As discussed previously, there are three general approaches which can be used to reduce residual nitrogen. They are 1) reduction of the quantity of commercial inorganic nitrogen used, 2) timing of the application of nitrogen fertilizer to maximize uptake by crop, and 3) using alternative (organic) forms of nitrogen fertilizer. In the first case, input levels are changed while the production function remains the same. In cases 2 and 3, however, an alternative production function underlies production decisions, and the profit-maximizing combination of inputs changes.

### *Reduced Nitrogen Fertilizer*

When the producer is operating according to the production function

$$q = f(N,I), \qquad [3.6]$$

as stated above, profits are maximized at the point where

$$VMP_N = P_N \qquad [3.7]$$

and

$$VMP_I = P_I. \qquad [3.8]$$

The input substitution principle recognizes that, if the producer reduces the quantity of nitrogen fertilizer used, other inputs can be substituted for $N$ to maintain the initial level of output. As shown in figure 3.1, substituting $I$ for $N$ will maintain output at $q_1$ but will result in a movement away from the profit-maximizing level of $N$. At point A in figure 3.1, when $N = N_1$ and $I = I_1$,

$$RTS_{I,N} = \frac{P_N}{P_I}, \qquad [3.9]$$

and profits are at a maximum. If $N$ is reduced to $N_2$ and $I$ is increased to $I_2$, output is maintained at $q_1$.

However, at point B,

$$RTS_{I,N} > \frac{P_N}{P_I}, \qquad [3.10]$$

or

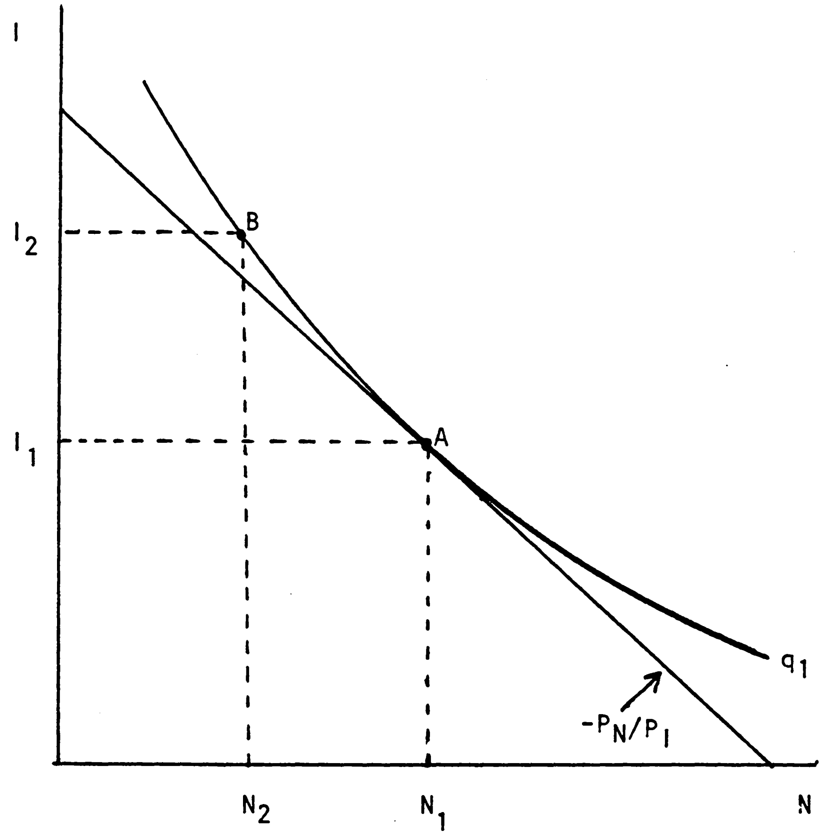

Figure 3.1. Impact of Reducing Nitrogen Fertilizer at Constant Prices

$$\frac{\mathrm{MP}_{N2}}{\mathrm{MP}_{I2}} > \frac{\mathrm{MP}_{N1}}{\mathrm{MP}_{I2}}. \qquad [3.11]$$

With constant output price, then,

$$VMP_{N2} > P_N. \qquad [3.12]$$

Profit is not maximized because adding an additional unit of $N$ would increase total profits by an amount greater than the unit cost of the additional $N$. This suggests that the profit-maximizing producer would not choose to reduce $N$ use, given this production function and input price ratio, as an approach to reducing nitrogen residuals.

### *Timing of Nitrogen Applications*

If the producer considers changing the timing of nitrogen applications, the relevant production function becomes

$$q = f(N,I,S) \qquad [3.13]$$

where $N$ is inorganic nitrogen fertilizer, $I$ is all other inputs, and $S$ is the subset of $I$ directly associated with the split application activity (e.g. labor, management, equipment). In the case with three variable inputs, the profit maximizing input combination continues to exist where

$$VMP_N = P_N, \qquad [3.14]$$

$$VMP_S = P_S, \qquad [3.15]$$

and

$$VMP_I = P_I. \qquad [3.16]$$

As figure 3.2 portrays, the production function suggests that $N$ can be reduced from the amount used in the conventional system without reducing total output, all other inputs held con-

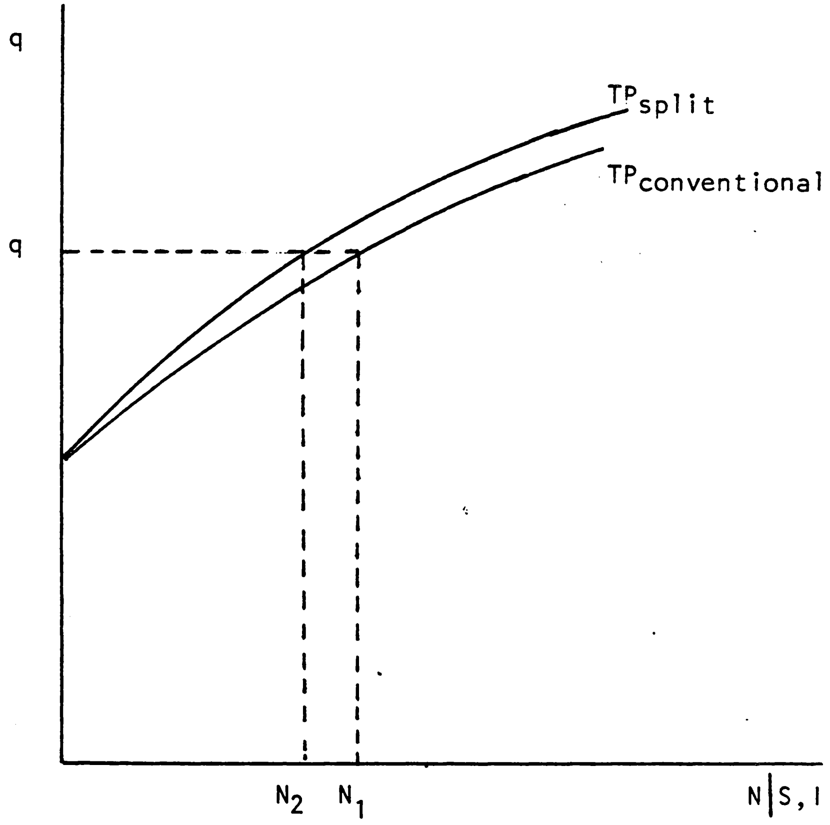

Figure 3.2. Change in Production Function When Split Nitrogen System is Used

stant. This results because the alternative technology, split $N$ application, changes the technical relationship between $N$ and $q$; $N$ can be reduced since the split application increases the proportion of applied $N$ which is used by the crop.

Other inputs such as labor, management and equipment ($S$) will be substituted for the $N$ eliminated. As shown in figure 3.3, a change in production technologies is represented by a change in the shape of the isoquants. For the split $N$ application technology, $S$ is substituted for $N$ while maintaining the same level of output. For the alternative technology, $N$ and $S$ are used so that the $RTS$ for all pairs of inputs equals the ratio of their prices. Also,

$$VMP_N = P_N, \qquad [3.17]$$

$$VMP_S = P_S, \qquad [3.18]$$

and

$$VMP_I = P_I, \qquad [3.19]$$

and profit is maximized.

If the producer is considering a split nitrogen application system, his decision is based on the relative profitability of the split application and conventional systems. The profit maximizing level and combination of inputs is determined for each system and the system which returns the highest profits is chosen.

## *Alternative Forms of Nitrogen*

The use of an alternative organic source of nitrogen represents yet another production technology. To simplify, consider the use of a legume cover crop as an organic source of nitrogen. The production function is

$$q = f(N,O,IO,I), \qquad [3.20]$$

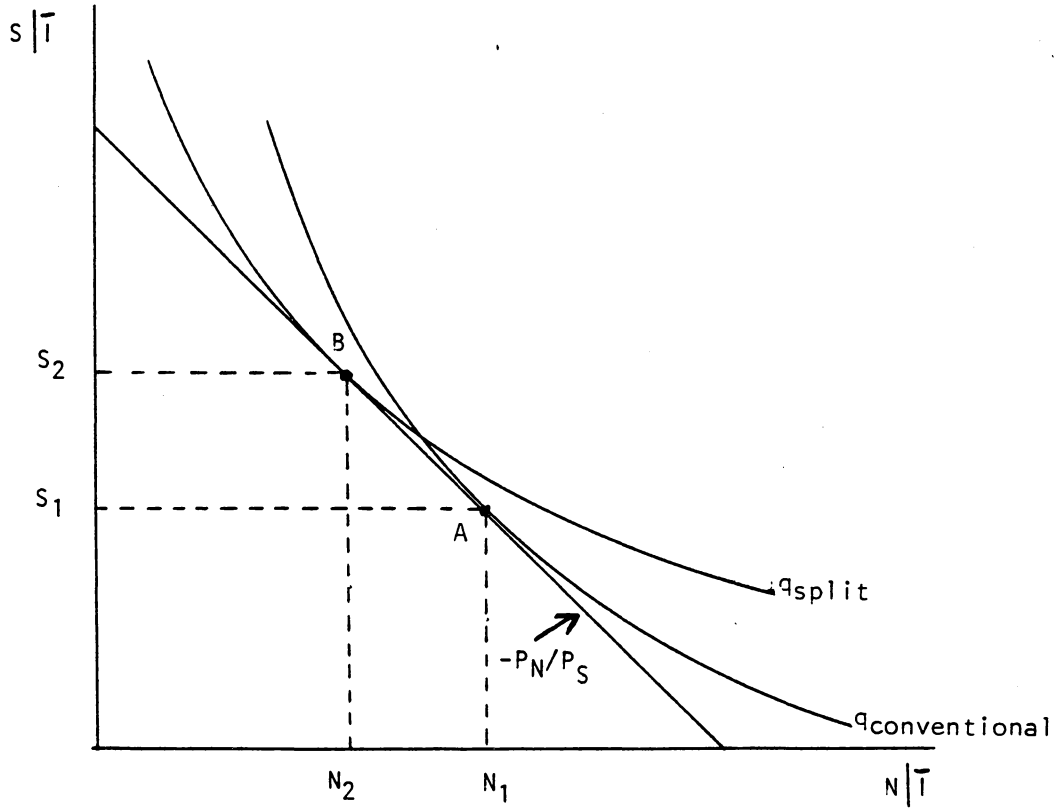

Figure 3.3. Isoquants for Two Different Production Functions and Two Different Profit-Maximizing Levels of Nitrogen

where $N$ is inorganic commercial nitrogen fertilizer, $O$ is organic nitrogen from the legume, $IO$ is other inputs directly associated with the use of $O$ (e.g. legume seed, labor, management, equipment), and $I$ is all other inputs. However, while a single period analysis is appropriate for inorganic nitrogen, organic nitrogen requires a multi-period perspective. A legume planted in period one will provide nitrogen in period two and in subsequent periods until the decay process is completed.

The single period production function assumes that all inputs applied in a given period are represented in output in that period. However, as the nitrogen balance model demonstrates, organic nitrogen inputs will be carried over to future periods, at which time they will be represented in one of the nitrogen outlets from the production system. The multi- period production function relates the input and output levels for all periods within the producer's planning horizon. Using this multi-period approach, it is possible to determine the marginal contributions of organic nitrogen to output levels in future periods.

The use of legume nitrogen as a production input can be represented by the following multi-period production function:

$$q_t = f(N_t, O_{t-1}, O_{t-2,\dots,} O_{t-n,} IO_{t-1}, IO_{t-2,\dots,} IO_{t-n,} I_t), \qquad [3.21]$$

where $t$ is the current production period and $n$ is the number of previous production periods contributing nitrogen. For the multi-period production function,

$$\mathrm{MP}_O = \frac{\delta q_{t+1}}{\delta O_t} + \frac{\delta q_{t+2}}{\delta O_t} + \dots + \frac{\delta q_{t+n}}{\delta O_t}, \qquad [3.22]$$

where $t$ is the production period when the legume is planted and $n$ is the number of subsequent production periods to which the legume will provide nitrogen.

The producer can maximize profits subject to the multi- period production function in a manner similar to that described for the single period case. That is, profits are maximized when, for each pair of inputs, the $RTS$ equals the ratio of their prices. The differences which arise are the incorporation of the multi-period marginal relations into the profit maximization criteria and the use of present values of input and output prices. The profit maximizing producer, then, chooses the input combinations which maximize the present value of his profit stream.

In converting to a nitrogen management system which uses a legume source of nitrogen, profits may take an initial decline to reflect the cost of seeding the first legume crop. However, a subsequent reduction in the need for inorganic nitrogen fertilizers, because of the carryover of organic nitrogen, will likely result in an increase in profits in later periods. This suggests that conversion to such a system might be viewed as an investment decision. The legume crop will be planted as a source of nitrogen if the present value of revenues from its use is greater than the costs incurred in its use, and the present value of net returns is higher than the present value of net returns from the current system over the same time period.

## Farm Level Nitrogen Management Decisions - An Empirical Model

An individual producer may choose from a number of different production systems, each of which incorporates a specific nitrogen management strategy. The producer's decision problem is to determine which system, at the profit-maximizing level of production, results in the greatest net returns. Linear programming (LP) is the mathematical optimization technique used to determine the optimal solution to this decision problem. Because of the carryover characteristics of organic sources of nitrogen and to reflect any physical adjustment period associated with the conversion to a new nitrogen management system, a multi- period model is used.

### *The Linear Programming Model*

The multi-period LP model used in this study consists of the objective function, model activities, resource constraints and the nitrogen balance sub-model.

#### The Objective Function

The objective of the multi-period LP model is to maximize the present value of net returns to farm level production over a ten year planning horizon. A ten year horizon is used to account for the build-up and use of organic matter in the soil and its impact on nitrogen requirements which will result from the use of organic nitrogen fertilizers. The annual returns include returns above variable costs only, including seed, fertilizers, pesticides, hired labor, and equipment operating costs. The fixed costs associated with operator labor, operator management, land, and equipment are not included in the model, i.e. returns are to these fixed factors.

**The Model Activities**

The activities in the model include production, marketing, purchasing, and transfer activities. The production activities consist of seven production systems, each of which reflects an alternative nitrogen management strategy.[2] The *conventional production system* (CONV) reflects the current system for grain production in the study area. In the study area, a two year, three crop rotation is common, consisting of corn and double-cropped small grains (wheat and barley) and soybeans (C/SM.GR.-SB). Corn is planted using minimum tillage. Conventional tillage is used for small grains, and soybeans are no-tilled into small grain stubble.

Weeds are controlled with herbicides on the minimum tillage and no-till acreage; spraying is done when a weed problem is realized rather than on a pre-planned schedule. Similarly, insect pests are controlled chemically, and insecticide use is based on a program of scouting and spraying target pests when a threshold level of infestation is reached. All pesticides are applied according to extension service and pesticide label specifications. Nitrogen, phosphorus ($P_2O_5$), and potassium ($K_2O$) are custom applied prior to planting by a fertilizer dealer. $P_2O_5$ and $K_2O$ rates are based on soil test results and crop requirements. Generally, nitrogen rates are based on the crop requirements for achieving a specific yield, based on previous crop yields. (Crop requirements for nitrogen are presented in Appendix B.2.)

The CONV system production activity is defined to include the crop rotation, tillage, pesticide and fertilizer practices described for the current system in use in the study area. For the CONV system, pesticide use is defined according to an average producer's use of pesticides, and all pesticides are custom applied by a chemical dealer. $P_2O_5$ and $K_2O$ use is defined according to a typical

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[2] The production systems were identified based on conversations with Extension agents in the study area and Extension specialists at Virginia Tech.

soil test and extension recommendation in the study area. N requirements are based on expected crop yields. All nutrients are also custom applied.

Producers in the study area use a number of soil conservation practices. The CONV system is defined to include, in addition to the reduced tillage practices, contour planting of all crops. This assumption is based on the "Alternative Conservation Systems" being followed by the Soil Conservation Service in the study area, in conjunction with the conservation planning required by the 1985 farm bill (USDA Soil Conservation Service).

The *split nitrogen system* (SPLN) differs from the CONV system only in the splitting of inorganic nitrogen fertilizer applications. Nitrogen fertilizer for corn is split into two separate applications; a small amount is applied at planting and the rest is applied 25 to 30 days after the plants emerge (Martin et al.). For wheat, a small amount of nitrogen is applied at planting. Then, in the spring, nitrogen is applied when the plants reach growth stage 25 and again at growth stage 45 (Alley et al.).[3] As discussed in chapter two, this split application of nitrogen assures that application of the largest amount of nitrogen coincides with the crop's period of greatest nitrogen use.

The *non-legume winter cover system* (WC) differs from the CONV system only in the planting of a winter cover crop of rye following soybean harvest. The rye cover crop serves as a sink for inorganic nitrogen remaining in the soil after harvest of the grain crops. The rye is disked under in March prior to the planting of the subsequent corn crop to allow it to decay sufficiently to release the stored nitrogen for use by the corn.

The *legume winter cover system* (LWC) differs from the CONV system in the following ways. A cover crop of crimson clover is planted immediately upon harvest of the soybean crop. An earlier season soybean variety is planted so that it is harvested earlier and the clover can be planted and a good stand achieved before winter. The clover is disked under two weeks prior to the planting of corn to allow decay of the clover to proceed sufficiently to release nitrogen for the corn. Inorganic nitrogen is custom applied, when needed, to supplement the nitrogen from the legume crop.

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[3] At growth stage 25, the wheat plant has developed the main shoot and five tillers. At growth stage 45, the boot is swollen (Alley et al.).

The *alternative rotation system* (AR) is based on a four year rotation which substitutes a year of a full season soybean for a year of corn (C/SM.GR.-SB/SB/SM.GR.-SB). This reduces the requirements of the system for added nitrogen. The full season soybean is produced using minimum tillage. All other aspects of the production system are similar to the conventional system.

The *alternative rotation/winter cover* (AR/WC) system is identical to the AR system, with these exceptions. A rye cover crop is planted in the fall before the spring planting of the full season soybean. A crimson clover cover crop is planted in the fall before the spring planting of corn. Again, a shorter season soybean is used in the year when a legume cover is planted to allow the legume to be planted early enough to get a good stand before winter. The cover crops are plowed under prior to planting the subsequent crops (rye in March, clover two weeks before planting corn) so that the decay process will release sufficient nitrogen for the following crops. Again, inorganic nitrogen is custom applied, when needed, to supplement the legume nitrogen.

The *poultry litter system* (PL) is identical to the CONV system with these exceptions. Poultry litter is applied to cropland and incorporated prior to the planting of the corn and small grain crops to supply nitrogen to these crops. The applications of $P_2O_5$ and $K_2O$ are reduced according to the nutrient content of the litter.

The use of livestock manure (other than poultry) was not considered in the analysis. There is very little livestock production in the study area, and thus a limited availability of manure as a source of nitrogen. Although there is not a ready supply of poultry litter in the study area either, there are studies underway to examine the feasibility of transporting poultry litter from intensive poultry producing areas into the grain producing area of eastern Virginia (Napit; Weaver et al.).

The marketing and purchase activities are included for the selling of grain crops and the purchase of nitrogen fertilizer and labor. Corn, small grains and soybeans are sold at harvest.

## Resource Constraints

The resource constraints used in the model are associated with land resources and operator labor. Cropland acreage restrictions are based on the average farm size in the study area, and acreage is assumed to be constant. The labor restriction is divided into monthly restrictions for each year. Operating capital is not restricted; it is assumed that operating capital is borrowed and unlimited funds are available at constant cost.

## The Nitrogen Balance Sub-model

The nitrogen balance sub-model is incorporated into the LP model to account for nitrogen inputs to, nitrogen storage in, and nitrogen outputs from the production systems. The sub-model is linked to the LP model by the nitrogen requirements of the production systems. The requirements are satisfied by nitrogen inputs including nitrogen availability from the mineralization of soil nitrogen, nitrogen fixation by legume crops, mineralization of nitrogen from stored organic nitrogen, and external inorganic and organic nitrogen fertilizer additions. Additions of external nitrogen are based on crop requirements above soil nitrogen, fixed nitrogen, and carryover. Nitrogen storage from year to year depends on the source of nitrogen fertilizer and decay rates of organic matter. Nitrogen outputs in the model include 1) crop uptake and crop harvest and 2) residual nitrogen.

There is no attempt, within the framework of the model, to determine the eventual fate of residual nitrogen. All of the residual nitrogen, as calculated by the nitrogen balance model, will not be found in runoff or nitrogen loading to groundwater. However, residual nitrogen is being used as an indicator of potential ground or surface water contamination. With additional information, the possible fate of residual nitrogen in the study area can be hypothesized. Gaseous losses of nitrogen can be minimized with the appropriate application techniques, and denitrification is negligible in the light, sandy soils in eastern Virginia. With adequate erosion control practices, erosion and runoff losses are minimized. However, the soils in the study area are well drained, sandy soils which are especially conducive to leaching of nitrogen. The water table in the area is relatively high, and return flows to the Bay and its tributaries will easily transport leached nutrients into surface water. Thus, calculation of residual nitrogen levels using the mass balance approach provides information as to the potential for nitrate pollution in the Chesapeake Bay drainage.

## The Optimization Model

The LP model is presented in tableau form in figure 3.4. The columns of the tableau represent the production, purchasing, marketing and transfer activities in the model. Total availability of land and operator labor are listed in the **RHS** column.

The objective function for the model is described in the **RETURNS** row. The structure of the model is such that net returns are calculated for each time period ( **NRET** ) and then transferred, adjusted by the appropriate discount factor, into the objective function.

The land, labor, capital and nitrogen requirements for each system are included in the rows section. Also included in this section is the quantity of each grain crop produced by each system and the transfer of nitrogen from one period to the next. The nitrogen balance sub-model, summarized in figure 3.4, is presented in more detail in figure 3.5. A separate tableau is presented for systems using only inorganic nitrogen (3.5a), systems using legume nitrogen (3.5b), and the poultry litter system (3.5c).

The storage of nitrogen from one period to the next and its subsequent availability for plant growth are indicated in the rows which account for nitrogen uptake by the crops ( **NUP** ), for crop residue nitrogen production ( **REN** ), and for legume cover crop nitrogen production ( **LGN** ). The number of subsequent time periods linked by these rows to one particular period depends upon the source of nitrogen applied and how rapidly it becomes available to the crop. The nitrogen balance sub-model matrix for the poultry litter system differs slightly from that of other systems since litter is supplied by the ton, and nitrogen availability is inferred from the amount of litter supplied.

A key to the tableaux in figures 3.4 and 3.5 is presented in table 3.1. The row and column names are defined, and the technical coefficients are explained. The technical coefficients for the model define the relationship between a given activity and a given constraint. The values of the model coefficients and their estimation are presented below.

### *Estimation of Technical Coefficients*

The optimization model developed to analyze farm level nitrogen management decisions in-

|  | RET1t | PS1t | Ct | Wt | Bt | SBt | MARt | APRt | MAYt | JUNt | SEPt | OCTt | NOVt | INTt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RETURNS | -d |  |  |  |  |  |  |  |  |  |  |  |  |  |
| NRET1t | -1 | -r | r | r | r | r | -r | -r | -r | -r | -r | -r | -r | -r |
| LANDt |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |
| CAPt |  | K |  |  |  |  | K | K | K | K | K | K | K | -1 |
| LMARt |  | ma |  |  |  |  | -1 |  |  |  |  |  |  |  |
| LAt |  | a |  |  |  |  |  | -1 |  |  |  |  |  |  |
| LMt |  | m |  |  |  |  |  |  | -1 |  |  |  |  |  |
| LJt |  | j |  |  |  |  |  |  |  | -1 |  |  |  |  |
| LSt |  | s |  |  |  |  |  |  |  |  | -1 |  |  |  |
| LOt |  | o |  |  |  |  |  |  |  |  |  | -1 |  |  |
| LNt |  | n |  |  |  |  |  |  |  |  |  |  | -1 |  |
| CORNt |  | -c | 1 |  |  |  |  |  |  |  |  |  |  |  |
| WHTt |  | -w |  | 1 |  |  |  |  |  |  |  |  |  |  |
| BARt |  | -b |  |  | 1 |  |  |  |  |  |  |  |  |  |
| SOYt |  | -sb |  |  |  | 1 |  |  |  |  |  |  |  |  |
| SON1t |  | sn |  |  |  |  |  |  |  |  |  |  |  |  |
| FIN1t |  | fn |  |  |  |  |  |  |  |  |  |  |  |  |
| CARN1t |  | can |  |  |  |  |  |  |  |  |  |  |  |  |
| NUP1t |  | NR |  |  |  |  |  |  |  |  |  |  |  |  |
| IMN1t |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| REN1t |  | rn |  |  |  |  |  |  |  |  |  |  |  |  |
| LGN1t |  | 1n |  |  |  |  |  |  |  |  |  |  |  |  |
| NRES1t |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| NPL1t |  | po |  |  |  |  |  |  |  |  |  |  |  |  |
| POT1t |  | ph |  |  |  |  |  |  |  |  |  |  |  |  |
| PHO1t |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

Figure 3.4. Linear Programming Model Tableau

| | SNit | FNit | CONit | PNit | RNit | TNit | LNit | RESit | POLit | PLNit | Kt | Pt | | RHS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RETURNS | | | | | | | | | | | | | | |
| NRETit | | | | -r | | | | | -r | | -r | -r | EQ | 0 |
| LANDt | | | | | | | | | | | | | LE | L |
| CAPt | | | | K | | | | | K | | K | K | LE | 0 |
| LMARt | | | | | | | | | | | | | LE | Ma |
| LAt | | | | | | | | | | | | | LE | A |
| LMt | | | | | | | | | | | | | LE | M |
| LJt | | | | | | | | | | | | | LE | J |
| LSt | | | | | | | | | | | | | LE | S |
| LOt | | | | | | | | | | | | | LE | 0 |
| LNt | | | | | | | | | | | | | LE | N |
| CORNt | | | | | | | | | | | | | EQ | 0 |
| WHTt | | | | | | | | | | | | | EQ | 0 |
| BARt | | | | | | | | | | | | | EQ | 0 |
| SOYt | | | | | | | | | | | | | EQ | 0 |
| SONit | -1 | | | | | | | | | | | | EQ | 0 |
| FINit | | -1 | | | | | | | | | | | EQ | 0 |
| CARNit | -1 | -1 | -1 | | | | | | | | | | EQ | 0 |
| NUPit | | | | -p | | | | | | -pp | | | LE | 0 |
| IMNit | | | | h | | -1 | | | | | | | EQ | 0 |
| RENit | | | | | -1 | | | | | | | | EQ | 0 |
| LGNit | | | | | | | -1 | | | | | | EQ | 0 |
| NRESit | | | | x | x | | | -1 | | x | | | EQ | 0 |
| NPLit | | | | | | | | | -1bn | 1 | | | EQ | 0 |
| POTit | | | | | | | | | -1bk | | -1 | | LE | 0 |
| PHOit | | | | | | | | | -1bp | | | -1 | LE | 0 |

Figure 3.4. (continued)

| | PS11 | PS12 | PS13 | PS14 | SN11 | FN11 | CON11 | PN11 | RN11 | TN11 | SN12 | FN12 | CON12 | PN12 | RN12 | TN12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SON11 | sn | | | | -1 | | | | | | | | | | | |
| FIN11 | fn | | | | | -1 | | | | | | | | | | |
| CARN11 | can | | | | | | -1 | | | | | | | | | |
| NUP11 | NR | | | | -1 | -1 | -1 | -p | | | | | | | | |
| REN11 | rn | | | | | | | | -1 | | | | | | | |
| IMN11 | | sn | | | | | | h | | -1 | | | | | | |
| SON12 | | fn | | | | | | | | | -1 | | | | | |
| FIN12 | | can | | | | | | | | | | -1 | | | | |
| CARN12 | | NR | | | | | | | | | | | -1 | | | |
| NUP12 | | rn | | | | | | | -pr | -1 | -1 | -1 | -1 | -p | | |
| REN12 | | | sn | | | | | | | | | | | | -1 | |
| IMN12 | | | fn | | | | | | | | | | | h | | -1 |
| SON13 | | | can | | | | | | | | | | | | | |
| FIN13 | | | NR | | | | | | | | | | | | | |
| CARN13 | | | rn | | | | | | | | | | | | | |
| NUP13 | | | | sn | | | | | -pr | | | | | | -pr | -1 |
| REN13 | | | | fn | | | | | | | | | | | | |
| IMN13 | | | | NR | | | | | | | | | | | | |
| SON14 | | | | rn | | | | | | | | | | | | |
| FIN14 | | | | | | | | | | | | | | | | |
| NUP14 | | | | | | | | | -pr | | | | | | -pr | |
| REN14 | | | | | | | | | | | | | | | | |
| IMN14 | | | | | | | | | | | | | | | | |
| NRES11 | | | | | | | | x | x | | | | | | | |
| NRES12 | | | | | | | | | | | | | | x | x | |
| NRES13 | | | | | | | | | | | | | | | | |
| NRES14 | | | | | | | | | | | | | | | | |

Figure 3.5.a. Nitrogen Sub-model Tableau - General

| | SN13 | FN13 | CON13 | PN13 | RN13 | TN13 | SN14 | FN14 | PN14 | RN14 | TN14 | RES11 | RES12 | RES13 | RES14 | | RHS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SON11 | | | | | | | | | | | | | | | | EQ | 0 |
| FIN11 | | | | | | | | | | | | | | | | EQ | 0 |
| CARN11 | | | | | | | | | | | | | | | | EQ | 0 |
| NUP11 | | | | | | | | | | | | | | | | LE | 0 |
| REN11 | | | | | | | | | | | | | | | | EQ | 0 |
| IMN11 | | | | | | | | | | | | | | | | EQ | 0 |
| SON12 | | | | | | | | | | | | | | | | EQ | 0 |
| FIN12 | | | | | | | | | | | | | | | | EQ | 0 |
| CARN12 | | | | | | | | | | | | | | | | EQ | 0 |
| NUP12 | | | | | | | | | | | | | | | | LE | 0 |
| REN12 | | | | | | | | | | | | | | | | EQ | 0 |
| IMN12 | | | | | | | | | | | | | | | | EQ | 0 |
| SON13 | -1 | | | | | | | | | | | | | | | EQ | 0 |
| FIN13 | | -1 | | | | | | | | | | | | | | EQ | 0 |
| CARN13 | | | -1 | | | | | | | | | | | | | EQ | 0 |
| NUP13 | -1 | -1 | -1 | -p | | | | | | | | | | | | LE | 0 |
| REN13 | | | | | -1 | | | | | | | | | | | EQ | 0 |
| IMN13 | | | | h | | -1 | | | | | | | | | | EQ | 0 |
| SON14 | | | | | | | -1 | | | | | | | | | EQ | 0 |
| FIN14 | | | | | | | | -1 | | | | | | | | EQ | 0 |
| NUP14 | | | | | -pr | -1 | -1 | -1 | -p | | | | | | | LE | 0 |
| REN14 | | | | | | | | | | -1 | | | | | | EQ | 0 |
| IMN14 | | | | | | | | | h | | -1 | | | | | EQ | 0 |
| NRES11 | | | | | | | | | | | | -1 | | | | EQ | 0 |
| NRES12 | | | | | | | | | | | | | -1 | | | EQ | 0 |
| NRES13 | | | | x | x | | | | | | | | | -1 | | EQ | 0 |
| NRES14 | | | | | | | | | x | x | | | | | -1 | EQ | 0 |

Figure 3.5.a. (continued)

| | PS11 | PS12 | PS13 | PS14 | SN11 | FN11 | CON11 | PN11 | RN11 | LN11 | TN11 | SN12 | FN12 | CON12 | PN12 | RN12 | LN12 | TN12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SON11 | sn | | | | -1 | | | | | | | | | | | | | |
| FIN11 | fn | | | | | -1 | | | | | | | | | | | | |
| CARN11 | can | | | | | | -1 | | | | | | | | | | | |
| NUP11 | NR | | | | -1 | -1 | -1 | -p | | | | | | | | | | |
| REN11 | rn | | | | | | | | -1 | | | | | | | | | |
| LGN11 | ln | | | | | | | | | -1 | | | | | | | | |
| IMN11 | | sn | | | | | | h | | | -1 | | | | | | | |
| SON12 | | fn | | | | | | | | | | -1 | | | | | | |
| FIN12 | | can | | | | | | | | | | | -1 | | | | | |
| CARN12 | | NR | | | | | | | | | | | | -1 | | | | |
| NUP12 | | rn | | | | | | | -pr | -pl | -1 | -1 | -1 | -1 | -p | | | |
| REN12 | | ln | | | | | | | | | | | | | | -1 | | |
| LGN12 | | | sn | | | | | | | | | | | | | | -1 | |
| IMN12 | | | fn | | | | | | | | | | | | h | | | -1 |
| SON13 | | | can | | | | | | | | | | | | | | | |
| FIN13 | | | NR | | | | | | | | | | | | | | | |
| CARN13 | | | rn | | | | | | | | | | | | | | | |
| NUP13 | | | ln | | | | | | -pr | -pl | | | | | | -pr | -pl | -1 |
| REN13 | | | | sn | | | | | | | | | | | | | | |
| LGN13 | | | | fn | | | | | | | | | | | | | | |
| IMN13 | | | | NR | | | | | | | | | | | | | | |
| SON14 | | | | rn | | | | | | | | | | | | | | |
| FIN14 | | | | ln | | | | | | | | | | | | | | |
| NUP14 | | | | | | | | | -pr | -pl | | | | | | -pr | -pl | |
| REN14 | | | | | | | | | | | | | | | | | | |
| LGN14 | | | | | | | | | | | | | | | | | | |
| IMN14 | | | | | | | | | | | | | | | | | | |
| NRES11 | | | | | | | | x | x | x | | | | | | | | |
| NRES12 | | | | | | | | | | | | | | | x | x | x | |
| NRES13 | | | | | | | | | | | | | | | | | | |
| NRES14 | | | | | | | | | | | | | | | | | | |

Figure 3.5.b. Nitrogen Sub-model Tableau - Legume System

|  | SN13 | FN13 | CON13 | PN13 | RN13 | LN13 | TN13 | SN14 | FN14 | PN14 | RN14 | LN14 | TN14 | RES11 | RES12 | RES13 | RES14 |  | RHS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SON11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| FIN11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| CARN11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| NUP11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| REN11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | LE | 0 |
| LGN11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| IMN11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| SON12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| FIN12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| CARN12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| NUP12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| REN12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | LE | 0 |
| LGN12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| IMN12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| SON13 | -1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| FIN13 |  | -1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| CARN13 |  |  | -1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| NUP13 | -1 | -1 | -1 | -p |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| REN13 |  |  |  |  | -1 |  |  |  |  |  |  |  |  |  |  |  |  | LE | 0 |
| LGN13 |  |  |  |  |  | -1 |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| IMN13 |  |  |  | h |  |  | -1 |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| SON14 |  |  |  |  |  |  |  | -1 |  |  |  |  |  |  |  |  |  | EQ | 0 |
| FIN14 |  |  |  |  |  |  |  |  | -1 |  |  |  |  |  |  |  |  | EQ | 0 |
| NUP14 |  |  |  |  | -pr | -pl | -1 | -1 | -1 | -p |  |  |  |  |  |  |  | EQ | 0 |
| REN14 |  |  |  |  |  |  |  |  |  |  | -1 |  |  |  |  |  |  | LE | 0 |
| LGN14 |  |  |  |  |  |  |  |  |  |  |  | -1 |  |  |  |  |  | EQ | 0 |
| IMN14 |  |  |  |  |  |  |  |  |  | h |  |  | -1 |  |  |  |  | EQ | 0 |
| NRES11 |  |  |  |  |  |  |  |  |  |  |  |  |  | -1 |  |  |  | EQ | 0 |
| NRES12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | -1 |  |  | EQ | 0 |
| NRES13 |  |  |  | x | x | x |  |  |  |  |  |  |  |  |  | -1 |  | EQ | 0 |
| NRES14 |  |  |  |  |  |  |  |  |  | x | x | x |  |  |  |  | -1 | EQ | 0 |

**Figure 3.5.b. (continued)**

| | PS11 | PS12 | PS13 | PS14 | SN11 | FN11 | CON11 | POL11 | PLN11 | RN11 | SN12 | FN12 | CON12 | POL12 | PLN12 | RN12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SON11 | sn | | | | -1 | | | | | | | | | | | |
| FIN11 | fn | | | | | -1 | | | | | | | | | | |
| CARN11 | can | | | | | | -1 | | | | | | | | | |
| NPL11 | | | | | | | | -1bn | 1 | | | | | | | |
| NUP11 | NR | | | | -1 | -1 | -1 | | -pp | | | | | | | |
| REN11 | rn | | | | | | | | | -1 | | | | | | |
| SON12 | | sn | | | | | | | | | -1 | | | | | |
| FIN12 | | fn | | | | | | | | | | -1 | | | | |
| CARN12 | | can | | | | | | | | | | | -1 | | | |
| NPL12 | | | | | | | | | | | | | | -1bn | 1 | |
| NUP12 | | NR | | | | | | | -pp | -pr | -1 | -1 | -1 | | -pp | |
| REN12 | | rn | | | | | | | | | | | | | | -1 |
| SON13 | | | sn | | | | | | | | | | | | | |
| FIN13 | | | fn | | | | | | | | | | | | | |
| CARN13 | | | can | | | | | | | | | | | | | |
| NPL13 | | | | | | | | | | | | | | | | |
| NUP13 | | | NR | | | | | | -pp | -pr | | | | | -pp | -pr |
| REN13 | | | rn | | | | | | | | | | | | | |
| SON14 | | | | sn | | | | | | | | | | | | |
| FIN14 | | | | fn | | | | | | | | | | | | |
| NPL14 | | | | | | | | | | | | | | | | |
| NUP14 | | | | NR | | | | | -pp | -pr | | | | | -pp | -pr |
| REN14 | | | | rn | | | | | | | | | | | | |
| NRES11 | | | | | | | | | x | x | | | | | | |
| NRES12 | | | | | | | | | | | | | | | x | x |
| NRES13 | | | | | | | | | | | | | | | | |
| NRES14 | | | | | | | | | | | | | | | | |

**Figure 3.5.c. Nitrogen Sub-model Tableau - Poultry Litter System**

|  | SN13 | FN13 | CON13 | POL13 | PLN13 | RN13 | SN14 | FN14 | POL14 | PLN14 | RN14 | RES11 | RES12 | RES13 | RES14 |  | RHS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SON11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| FIN11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| CARN11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| NPL11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| NUP11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | LE | 0 |
| REN11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| SON12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| FIN12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| CARN12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| NPL12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| NUP12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | LE | 0 |
| REN12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| SON13 | -1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| FIN13 |  | -1 |  |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| CARN13 |  |  | -1 |  |  |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| NPL13 |  |  |  | -1bn | 1 |  |  |  |  |  |  |  |  |  |  | EQ | 0 |
| NUP13 | -1 | -1 | -1 |  | -pp |  |  |  |  |  |  |  |  |  |  | LE | 0 |
| REN13 |  |  |  |  |  | -1 |  |  |  |  |  |  |  |  |  | EQ | 0 |
| SON14 |  |  |  |  |  |  | -1 |  |  |  |  |  |  |  |  | EQ | 0 |
| FIN14 |  |  |  |  |  |  |  | -1 |  |  |  |  |  |  |  | EQ | 0 |
| NPL14 |  |  |  |  |  |  |  |  | -1bn | 1 |  |  |  |  |  | EQ | 0 |
| NUP14 |  |  |  |  | -pp | -pr | -1 | -1 |  | -pp |  |  |  |  |  | LE | 0 |
| REN14 |  |  |  |  |  |  |  |  |  |  | -1 |  |  |  |  | EQ | 0 |
| NRES11 |  |  |  |  |  |  |  |  |  |  |  | -1 |  |  |  | EQ | 0 |
| NRES12 |  |  |  |  |  |  |  |  |  |  |  |  | -1 |  |  | EQ | 0 |
| NRES13 |  |  |  |  | x | x |  |  |  |  |  |  |  | -1 |  | EQ | 0 |
| NRES14 |  |  |  |  |  |  |  |  |  | x | x |  |  |  | -1 | EQ | 0 |

Figure 3.5.c. (continued)

## Table 3.1. Key to Tableaux

Subscripts

i = production system, described previously

t = time period (production year), t = 1-10

Columns

RET = transfer of total net returns to objective function

PS = production system activity (acre)

C = sale of corn (bushel)

W = sale of wheat (bushel)

B = sale of barley (bushel)

SB = sale of soybeans (bushel)

MAR = purchase of labor in March (hour)

APR = purchase of labor in April (hour)

MAY = purchase of labor in May (hour)

JUN = purchase of labor in June (hour)

SEP = purchase of labor in September (hour)

OCT = purchase of labor in October (hour)

NOV = purchase of labor in November (hour)

INT = interest costs on operating capital (dollar)

SN = use of soil nitrogen mineralized from soil organic matter (pound)

FN = use of nitrogen fixed by legume crops planted (pound)

CON = use of nitrogen stored from the pre-model period, for i = 1-3 only (pound)

PN = purchase of inorganic nitrogen fertilizer (pound)

RN = use of nitrogen stored in form of crop residues (pound)

TN = transfer of immobilized inorganic nitrogen fertilizer from period t to t+1 (pound)

LN = use of nitrogen from legume cover crop (pound)

RES = accounting of residual nitrogen

**Table 3.1 (continued)**

POL = purchase of poultry litter, for i = PL system only (ton)

PLN = transfer of nitrogen (pounds) from poultry litter

K = purchase of potassium, for i = PL system only (pound)

P = purchase of phosphorus, for i = PL system only (pound)

Rows

NRET = net returns

LAND = cropland

CAP = production capital

LMAR = operator labor in March

LA = operator labor in April

LM = operator labor in May

LJ = operator labor in June

LS = operator labor in September

LO = operator labor in October

LN = operator labor in November

CORN = transforms corn acres to bushels

WHT = transforms wheat acres to bushels

BAR = transforms barley acres to bushels

SOY = transforms soybean acres to bushels

SON = transformation of soil organic matter to plant available nitrogen

FIN = transformation row for nitrogen fixed by legume crop

CARN = transformation row for nitrogen available from pre-model period, i = 1-3 only

NUP = nitrogen taken up by crop

IMN = transfers immobilized inorganic nitrogen fertilizer to next period

REN = transformation row for crop residue nitrogen produced

LGN = transformation row for legume cover crop nitrogen produced

**Table 3.1 (continued)**

NRES = accounting of residual nitrogen

NPL = transforms tons of poultry litter to pounds of nitrogen

POT = transforms tons of poultry litter to pounds of K&sub.2O

PHO = transforms tons of poultry litter to pounds of P&sub.2O&sub.5

### Coefficients

d = the discount factor used to discount future returns to present value

r = the contribution of the activity to net returns (in current dollars)

K = the capital required (in current dollars) by the activity

ma = hours of labor required for the activity in March

a = hours of labor required for the activity in April

m = hours of labor required for the activity in May

j = hours of labor required for the activity in June

s = hours of labor required for the activity in September

o = hours of labor required for the activity in October

n = hours of labor required for the activity in November

c = the number of bushels of corn from an acre of the activity

w = the number of bushels of wheat from an acre of the activity

b = the number of bushels of barley from an acre of the activity

sb = the number of bushels of soybeans from an acre of the activity

sn = pounds of nitrogen available to an acre of the activity from soil organic matter

fn = pounds of nitrogen fixed by an acre of the activity

can = pounds of nitrogen available to the activity from the addition of nitrogen in periods prior to the modeled period

NR = pounds of nitrogen required by an acre of the activity

rn = pounds of nitrogen available to future periods in crop residue from an acre of the activity

ln = pounds of nitrogen available to future periods from legume cover crop

po = pounds of potassium required by an acre of the activity

ph = pounds of phosphorus required by an acre of the activity

**Table 3.1 (continued)**

p = the proportion of inorganic nitrogen fertilizer available to (used by) the crop

pr = the decay coefficient for nitrogen in crop residues

pl = the decay coefficient for nitrogen in legume green manure

pp = the decay coefficient for nitrogen in poultry litter

h = the proportion of inorganic nitrogen fertilizer immobilized and made available the following year

x = the proportion of nitrogen which goes to residual

lbn = the pounds of nitrogen in a ton of poultry litter

lbk = the pounds of potassium ($K_2O$) in a ton of poultry litter

lbp = the pounds of phosphorus ($P_2O_5$) in a ton of poultry litter

L = the maximum number of acres of cropland available

MA = the maximum number of hours of operator labor in March

A = the maximum number of hours of operator labor in April

M = the maximum number of hours of operator labor in May

J = the maximum number of hours of operator labor in June

S = the maximum number of hours of operator labor in September

O = the maximum number of hours of operator labor in October

N = the maximum number of hours of operator labor in November cludes the assumption that the technical relationships between inputs and outputs, the production costs, and the nitrogen balance process are understood and can be quantified. This section presents a detailed discussion of how the technical coefficients for the economic model were estimated. Included for each part of the discussion is a list of data sources used and a treatment of the informational or data problems associated with each type of coefficient. The actual data used for estimating each coefficient can be found in Appendices A and B (for the nitrogen sub-model).

**Objective Function and Net Returns (NRET) Row Coefficients**

The coefficients in the objective function are the discount factors used to adjust the net returns from each time period. A discount rate of 5 percent was used to reflect the real returns to capital assets in agriculture over the long run (Barry). Inflation was excluded since current prices were used for each time period in the model. Thus, for period t, the objective function coefficient is calculated as:

$$d_t = \frac{1}{(1 + .05)^{t-1}} \qquad [3.23]$$

For each time period, net returns before taxes were calculated for each system and transferred into the objective function. Net returns were calculated as

$$NRET_{it} = TR_{it} - TVC_{it} \qquad [3.24]$$

where $NRET_{it}$ = net returns from system $i$ in period $t$, $TR_{it}$ = total revenue from system $i$ in period $t$ as calculated from the marketing activity coefficients, and $TVC_{it}$ = total variable input costs for system $i$ in period $t$ as calculated from the production and purchasing activity coefficients.

The coefficients for the production activities were calculated on a composite per acre basis. The acreage of each crop in a system depends upon the rotation used in the system. For example, the two year rotation for an acre of the conventional system implies an acre of corn in one crop year, followed by an acre of double-cropped small grain and soybeans the second year. Equivalently, one-half acre of corn and one- half acre of double-cropped small grain and soybeans could be grown one crop year and, in the next crop year, the crops could be reversed on each half acre.

This is the approach followed for this study. In addition, based on current acreage in the study area, the one-half acre of small grain is further divided into .275 acres of wheat and .225 acres of barley.[4] Thus, a composite acre of the conventional system includes:

0.5 acres corn
0.275 acres wheat
0.225 acres barley
0.5 acres soybeans

The variable costs represented by the production system activity coefficients in the NRET row include seed, fertilizer (excluding nitrogen), lime, pesticide, and variable machinery costs. Using crop production budgets (Perkinson), costs for these inputs were calculated for an acre of each crop, and composite cost figures were calculated by weighting the production cost for each crop by its acreage proportion within the system. Total variable cost for seed, $P_2O_5$, $K_2O$, lime, pesticides, and machinery are shown in table 3.2 for each system.

**Table 3.2. Variable Input Costs, Per Acre, For Production Systems**

| System | Variable Input Costs |
|---|---|
| CONV | $134.72 |
| SPLN | 134.72 |
| WC | 143.81 |
| LWC | 145.58 |
| AR | 134.44 |
| AR/WC | 144.42 |
| PL | 104.09 |

---

[4] A farmer survey, to be discussed later, was used as a basis for determining crop acreage, as well as the size of the representative farm.

Purchasing activities include labor, nitrogen and operating capital purchases. Costs were included for purchased labor at a rate of $4.00 per hour, the current rate for hired labor in the study area (Perkinson). All operating capital was assumed to be borrowed, and an interest rate of 10.5 percent was used as the cost of borrowed capital. The rate being charged by Production Credit Associations for short term production loans varies between nine and 12 percent (Farm Credit Administration). The cost of inorganic nitrogen fertilizer is $.27 per pound, custom applied.

The input costs for the poultry litter system, shown in table 3.2, do not include the costs of $P_2O_5$ or $K_2O$. Because poultry litter contains substantial amounts of these nutrients, as well as nitrogen, the costs for $P_2O_5$ and $K_2O$ are included separately. Custom applied rates are $.28/lb for $P_2O_5$ and $.16/lb for $K_2O$ (Perkinson). The cost of poultry litter was calculated based on the experiences of the Virginia Cooperative Extension Service (Weaver et al; Collins et al.) in their experimental poultry litter backhauling project. According to their experience, the broker transporting and selling the litter generally will pay $5.00 per ton for the litter at its source. The cost of loading a 20 ton capacity tractor-trailer truck, based on the cost of renting a front-end loader, can be expected to run approximately $1.50 per ton. Hauling costs average $1.50 per loaded mile. Assuming a trip of 170 miles from the Shenendoah Valley to eastern Virginia, total costs of hauling will be $12.75/ton. A profit margin of $1.00 per ton has been assumed for the broker. This totals to a cost of $20.25 per ton delivered to the producer.

Total revenues are calculated from the prices received for the crops produced. The prices used were:

corn - $2.20/bushel
wheat - $2.73/bushel
barley - $1.94/bushel
soybeans - $6.24/bushel.

The corn and wheat prices were calculated from futures prices adjusted for basis, according to the formula

Cash price = Futures price + Basis (Kenyon).

The soybean and barley prices were calculated as an average of historical prices (Virginia Agricultural Statistics Service). The futures price for soybeans was not used because this year's futures price reflects the drought conditions. A more representative or "average" price was used to reflect a more normal situation.

### Constraint Coefficients

The land and labor constraint coefficients were estimated based on data available for the study area and for the state as a whole. A total of 500 acres of cropland was used as the land constraint and reflects the average number of cropland acres operated by a full-time farmer in the study area. The constraints on operator labor were calculated from data published in Virginia Agricultural Statistics (1987) on the "average number of days suitable for fieldwork" for each month. These data, based on a survey of farm operators, give the average number of days each month during which fieldwork could be done without being hampered by rain and other weather factors. The operator labor constraints for a full-time farmer used in the model are:

March - 153 hours
April - 153 hours
May - 181 hours
June - 249 hours
September - 287 hours
October - 185 hours
November - 189 hours

Participation in government commodity programs was not considered in the model. For most of the production systems considered, crop rotations and acreages would not be changed in a way which would affect program participation. The AR and AR/WC systems would involve a change in corn acreage. However, in the study area, farmer participation in the wheat and feed grains programs is slight (Ligon et al.). Thus, the participation in commodity programs is not likely to impact the results of the analysis.

### Matrix Elements

This section deals with the matrix elements of the model tableau in figure 3.4. The elements in the **CAP** row indicate the capital costs associated with each production and purchase activity. For each activity, **K** equals the costs indicated for that activity in the **NRET** row.

The elements in the **LMAR, LA, LM, LJ, LS, LO,** and **LN** rows indicate the number of field hours required for each activity. The calculation of these coefficients were based on machinery budgets (Dunford et al.) and are presented in Appendix A.5.

The elements **c**, **w**, **b**, and **sb** are per acre yields of corn, wheat, barley and soybeans produced by an acre of a given system. The crop yields used are historical average yields for the study area ( Virginia Agricultural Statistics, various years) and are weighted by the acreage proportion of the crop in an acre of the system. The yields assumed for each system are given in Appendix A.2.

A fixed yield model is used in this study. Ideally, one would allow the input-output relationship between, say, nitrogen and crop yield and the relative prices to determine the optimal use of nitrogen and the optimal crop yield, ceteris paribus. However, incorporating this production function into the model used here is inhibited by the use of composite crops in the production activities. Estimated multi-crop production functions and the associated growth-response data are not available for the study area. Thus, the input-output relationship for a specific crop yield is used.

### Nitrogen Sub-model Matrix Elements

The elements in the sub-model matrix are based, primarily, on the discussion in chapter 2 and information on the climate, topography, and geology of the study area. In estimating the values for these coefficients, a typical crop year is assumed, including average temperature and rainfall levels. Also, a typical soil type for the study area is used when soil type is an important factor. A detailed explanation of the estimation of the elements in the nitrogen sub-model is in Appendix B.

For each system, the total amount of nitrogen available per acre from mineralization of soil organic matter is estimated and is represented by **sn** in figure 3.5. Most of the soil in the study area has an organic matter content of approximately one percent (Nicholson; Robinette and Hoppe). A one percent organic matter soil generally contains about five percent or 1000 pounds per acre of nitrogen (assuming a seven inch plow layer weighs 2,000,000 pounds). On average, three percent of that nitrogen becomes available to crops during the growing season (Ankerman and Large). Thus, 30 pounds per acre of nitrogen is assumed to be available from soil organic matter.

The total nitrogen fixed by soybeans depends on the yield. However, soybeans generally fix about 74 percent of their nitrogen content. Again, the value for **fn** is a function of the proportion of soybean acreage in an acre of a given system.

The nitrogen stored from production periods prior to the first period modeled is accounted for in the **CARN** row by the element **can**. The amount of nitrogen carried over from time periods prior to the modeled period was estimated by solving the model for the conventional system and determining the total nitrogen carryover for each period as estimated by the model. This value was then used for the **can** element for each system, since it is assumed that, regardless of the system used during the modeled period, the conventional system was used prior to the model period.

The nitrogen requirements of each system depend on the crop mix and assumed yields for each system. Since, within a reasonable yield range, nitrogen content of the crop varies linearly with crop yield, the nitrogen content of the harvested and residue portions of each crop could be calculated (Brann; Fried et al.). The nitrogen uptake (nitrogen in grain + nitrogen in stubble) for each crop was weighted to form a composite nitrogen requirement ( **NR** ) for each system.

The crop stubble left in the field contains a fixed amount of nitrogen, **rn**, which is calculated as part of the nitrogen requirement calculations. The total nitrogen in a legume cover crop, **ln**, is estimated based on results of previous research (Hargrove; Wagger). These computations can be found in Appendix B.3.

The phosphorus and potassium requirements for the system using poultry litter are incorporated into the model as separate elements, unlike the case with other systems. $P_2O_5$ and $K_2O$ requirements are based on the use of these nutrients by the crops in the system and extension recommendations as used in the production budgets.

Nitrogen availability from inorganic nitrogen fertilizer is represented by **p** in the matrix. When inorganic nitrogen is used, **p** is the proportion of total nitrogen used by the current crops. Based on the information in chapter two, 60 percent of applied inorganic nitrogen fertilizer is assumed to be used by the system (crop) to which it is applied when a single application is used (Keeney, 1986). For the split nitrogen application system, 80 percent of applied nitrogen is used by crops (Alley et al.).

As crop residues decay, inorganic nitrogen is released. The **pr** element in the nitrogen submodel matrix represents the decay of crop residues. A decay rate of .15, .05, .03 is used; that is, 15 percent of nitrogen in crop residues becomes available in the year following crop harvest. Five percent and three percent becomes available, respectively, in the second and third years. In the system with a rye winter cover crop, the decay rate differs slightly to reflect the lower C to N ratio in the cover crop residue.

Similarly, legume winter cover crops have a decay rate ( **pl** ) which determines the availability of nitrogen from the legume. A rate of .6, .1, .1, .05 is used; 60 percent of the legume nitrogen is available in the year after it is planted. Then, 10 percent is available in the second and third years and five percent is available in the fourth year.

The decay rate for nitrogen in poultry litter ( **pp** ) is .66, .072, .03, .012, .012. The 66 percent in year one includes the availability of inorganic nitrogen in the litter at the time it is applied. Then, as the organic matter decays, nitrogen becomes available at a slower rate in the second through the fifth years after application.

Of the inorganic nitrogen fertilizer applied, a certain amount is immobilized and then mineralized the following crop season (Keeney, 1986; Bartholomew). A value of two percent is used for this element ( **h** ) in the model.

For both inorganic and organic sources of nitrogen, a small amount of nitrogen will be permanently incorporated into soil organic matter (Brady; Stevenson and He). A value of 15 percent is used for each source of nitrogen. Thus, residual nitrogen includes the inorganic nitrogen fertilizer which is neither used by the current crop nor immobilized ( **x** ). For crop residues and organic sources of nitrogen, residual nitrogen is that nitrogen which is neither used by crops over the course of the decay period nor permanently incorporated into the soil organic matter ( **x** ).

The nitrogen, $P_2O_5$ and $K_2O$ content of poultry litter is based on average values from all poultry litter samples analyzed in the water quality lab in the Department of Agricultural Engineering in 1988. The analyses for dry broiler litter are used in the model. A ton of poultry litter is assumed to contain 58 pounds of total nitrogen, 40 pounds of $P_2O_5$, and 30 pounds of $K_2O$.

## *Scope of the Analysis*

The deterministic LP model used in this study does not account for the uncertainty associated with nitrogen movement and crop growth. While the literature-based coefficients used for the nitrogen balance sub-model are impacted by temperature, moisture, and other climate factors, the relationships between the different factors are not well known. The "point estimates" used in the model are representative of a typical situation, which makes the model results valid for such a situation. However, there is not sufficient information available to use a stochastic modeling approach and obtain reliable results.

## Summary

In this chapter, the theoretical foundations of producers′ decisions when faced with alternative technologies were reviewed and an empirical model of nitrogen management was presented. The LP model, as described in the previous section was solved for each production system. The resulting net returns, input use, and residual nitrogen levels are presented in the following chapter. Additionally, limitations of the model will be reviewed and their implications for interpreting the results discussed.

# Chapter 4

## *An Analysis of Alternative Nitrogen Management Strategies: Results and Discussion*

The first objective of this study, as stated in chapter one, is to identify and evaluate alternative production systems designed to manage the amount, timing and form of nitrogen fertilizer applications. The alternative systems were described in the previous chapter, and an economic optimization model was developed to evaluate the systems. In this chapter, the results of the economic analysis are presented.

### Model Results

The optimization model presented in the previous chapter was solved separately for each production system to compare the profit-maximizing level of net returns and input use and the resulting nitrogen residuals for each system. As discussed previously, constant crop yields were assumed for each system over time. A full-time, 500 acre grain production operation was used as the model farm.

#### *Net Returns to Alternative Systems*

In table 4.1, the net returns from each of the seven production systems are presented.

**Table 4.1. Annual Net Returns from Seven Production Systems, in Current Dollars, and Present Value of Net Returns (PVNR) Over Ten Years, Per Acre**

| | Production System | | | | | | |
|---|---|---|---|---|---|---|---|
| Year | CONV | SPLN | WC | LWC | AR | AR/WC | PL |
| 1 | 57.27 | 66.86 | 44.99 | 36.86 | 61.90 | 42.63 | 76.36 |
| 2 | 57.25 | 66.60 | 48.04 | 51.57 | 63.01 | 51.15 | 78.95 |
| 3 | 57.27 | 66.62 | 48.73 | 53.52 | 63.02 | 52.22 | 80.24 |
| 4 | 57.27 | 66.62 | 50.29 | 55.91 | 63.04 | 53.79 | 80.61 |
| 5 | 57.27 | 66.62 | 48.30 | 57.07 | 63.04 | 54.36 | 81.08 |
| 6 | 57.27 | 66.62 | 49.47 | 57.03 | 63.04 | 54.34 | 80.95 |
| 7 | 57.27 | 66.62 | 49.43 | 57.03 | 63.04 | 54.34 | 80.91 |
| 8 | 57.27 | 66.62 | 49.43 | 57.03 | 63.04 | 54.34 | 80.90 |
| 9 | 57.27 | 66.62 | 49.43 | 57.03 | 63.04 | 54.34 | 80.90 |
| 10 | 57.27 | 66.62 | 49.43 | 57.03 | 63.04 | 54.34 | 80.90 |
| PVNR | 464.31 | 540.36 | 394.20 | 432.91 | 509.90 | 423.44 | 648.86 |
| (index) | (100) | (116.4) | (84.9) | (93.2) | (109.8) | (91.2) | (139.8) |

For each system, annual net returns in constant dollars are presented for each of the 10 years in the planning period. Then, the present value of net returns (PVNR) over the entire 10 year period is presented for each system.

Economic theory asserts that the production system which, at its profit-maximizing point, results in the highest PVNR will be chosen by producers. Three of the alternative production systems considered result in a higher value of PVNR over the 10 year period than the *conventional system* (CONV). The *poultry litter system* (PL) has the highest PVNR, 40 percent higher than for the CONV system. The second highest level of PVNR is from the *split nitrogen application system*

(SPLN), which results in 16.4 percent higher returns. The *alternative rotation system* (AR) PVNR exceeds the CONV system returns by 10 percent.

The PVNR from the *legume winter cover system* (LWC) for the 10 year period is seven percent lower than PVNR from the CONV system. As shown in table 4.1, the LWC system stabilizes in the sixth year. In the sixth year and beyond, per acre returns from the LWC system and the CONV system are comparable. However, the initial decline in net returns in the early years and the discounting of net returns in later years combine to result in a lower level of PVNR. The initial decline in net returns results from the costs of seeding the legume cover crop and providing nitrogen fertilizer to crops in the first year. In the second year and beyond, the legume from the previous year(s) provides nitrogen so that nitrogen fertilizer requirements are substantially reduced.

The *alternative rotation/winter cover system* (AR/WC) results in 8.8 percent lower PVNR than the CONV system. Again, the initial cost of seeding the winter cover crops causes a decline in net returns. However, the legume winter cover provides nitrogen, which reduces total nitrogen requirements. The *non-legume winter cover system* (WC) results in a 15 percent lower level of PVNR than the CONV system. As with the LWC system, the initial costs of seeding the rye cover crop cause a substantial decline in net returns.

The net returns calculations do not include the costs associated with learning the alternative system: information seeking and gathering costs, costs associated with changing management styles or learning new management skills, costs associated with risk-reducing behavior during the transition period. If significant transition costs exist for converting to the alternative systems, then the PVNR for the alternative systems are overstated.

An additional factor which should be included in a complete accounting of net returns is the effect on land prices of any impact on soil fertility resulting from the conversion to an alternative nitrogen management strategy. It is not clear that such factors are capitalized into land values. However, for example, building up soil organic matter by using organic sources of nitrogen could be expected to enhance the long term productivity of the soil. This factor is not explicitly included in the model.

Differences in input use have the largest impact on the relative profitability of the alternative systems. In particular, the nitrogen and labor requirements of the alternative systems impact their profitability. The substantially higher level of PVNR from the PL system can be attributed to its input use. For example, each ton of poultry litter supplies nitrogen, $P_2O_5$ and $K_2O$ to crops. Thus, the costs for fertilizer are significantly reduced. Second, because minimum and conventional tillage practices are assumed for the corn and small grain crops, there is no additional cost for incorporating the litter. Once it is spread, incorporation is achieved in the usual tillage operations. Third, the carryover of organic nitrogen reduces the amount of additional nitrogen (poultry litter) required each year. Because of the organic nitrogen carryover and the $P_2O_5$ and $K_20$ content of the poultry litter, PVNR from the PL system exceeds PVNR from the CONV system until the price per ton of poultry litter exceeds $33.00.

The nitrogen balance for the PL system reaches an equilibrium in the seventh year, so that nitrogen carryover reaches a constant level, given a constant rate of litter application. In table 4.2, application rates of poultry litter for each of the 10 years is shown. Also shown is the amount of nitrogen, $P_2O_5$, and $K_2O$ applied in the poultry litter.

The SPLN system results in a higher level of PVNR because of the reduction in nitrogen fertilizer requirements. The CONV system requires 128.5 pounds per acre of inorganic nitrogen fertilizer to maintain crop yields at the specified level. Because more of the nitrogen which is applied in the SPLN system is used by the crop, the SPLN system requires only 66.62 pounds per acre of nitrogen fertilizer to maintain crop yields at the same level. The assumption that all nitrogen fertilizer is custom applied at a constant cost of $.27 per pound means that splitting nitrogen applications does not result in an increase in labor or machinery costs.

The AR system also requires lower nitrogen inputs than the CONV system, because of the increased proportion of soybean acreage in the system. The AR system uses 63 pounds per acre of nitrogen fertilizer each year. The lower nitrogen requirement reduces production costs and increases PVNR to the system over the PVNR from the CONV system.

As shown in table 4.3, nitrogen fertilizer requirements for the LWC system decline over the first five years. In the fifth year, nitrogen carryover levels reach an equilibrium and a constant

**Table 4.2. Annual Rates of Poultry Litter Application, Per Acre, to Provide Nitrogen to Maintain Crop Yields, and Nitrogen (N), P&sub2.O&sub5., and K&sub2.O Applied in the Litter**

| Year | Litter Applied (tons) | Total N (lbs/ton) | Total P&sub2.O&sub5. (lbs/ton) | Total K&sub2.O (lbs/ton) |
|---|---|---|---|---|
| 1 | 2.01 | 116.58 | 82.41 | 60.3 |
| 2 | 1.86 | 107.88 | 76.26 | 55.8 |
| 3 | 1.79 | 103.82 | 73.39 | 53.7 |
| 4 | 1.77 | 102.66 | 72.57 | 53.1 |
| 5 | 1.74 | 100.92 | 71.34 | 52.2 |
| 6 | 1.74 | 100.92 | 71.34 | 52.2 |
| 7 | 1.75 | 101.5 | 71.75 | 52.5 |
| 8 | 1.75 | 101.5 | 71.75 | 52.5 |
| 9 | 1.75 | 101.5 | 71.75 | 52.5 |
| 10 | 1.75 | 101.5 | 71.75 | 52.5 |

amount of nitrogen is released from organic residues each year, assuming the legume cover crop is planted and disked under every year. At the nitrogen balance equilibrium, 57 pounds per acre of nitrogen fertilizer are purchased. This compares to 128.5 pounds per acre for the CONV system.

The WC system does not provide additional nitrogen to crops but merely serves as a sink for a portion of the inorganic nitrogen fertilizer applied. Thus, nitrogen fertilizer requirements are not substantially reduced over time. As shown in table 4.3, the WC system requires the purchase of approximately 114 pounds per acre of nitrogen fertilizer to maintain crop yields.

Nitrogen requirements of the AR/WC system are lower because soybean acreage is larger and because of the legume winter cover crop. That the PVNR from the AR/WC is slightly lower than from the LWC system is probably due to the inclusion of the rye winter cover which, again, serves as a nitrogen sink but not as a source of additional nitrogen. Table 4.3 shows the yield maintaining nitrogen requirements of the AL/WC system.

**Table 4.3. Nitrogen Fertilizer Purchases, in Pounds Per Acre, for WC, LC and AR/WC Systems to Maintain Crop Yields**

| | System | | |
|---|---|---|---|
| Year | WC | LC | AR/WC |
| 1 | 128.5 | 125.5 | 85.8 |
| 2 | 118.3 | 76.2 | 57.3 |
| 3 | 116.0 | 69.7 | 53.7 |
| 4 | 110.8 | 61.7 | 48.4 |
| 5 | 117.4 | 57.8 | 46.5 |
| 6 | 113.5 | 57.9 | 46.6 |
| 7 | 113.6 | 57.9 | 46.6 |
| 8 | 113.6 | 57.9 | 46.6 |
| 9 | 113.6 | 57.9 | 46.6 |
| 10 | 113.6 | 57.9 | 46.6 |

Labor requirements for several systems are increased when compared to labor requirements of the CONV system, as shown in table 4.4. For each system, labor is purchased when operator labor constraints for a particular month are binding and additional labor is needed. Labor requirements for the CONV and SPLN systems are the same, since custom application of nitrogen fertilizer is assumed. For the WC system, labor needs exceed operator labor availability in those months when seeding of the cover crop occurs so that total labor purchased is higher. The LWC system requires additional operator and hired labor, as compared to the CONV system, to seed the cover crop.

The AR system requires approximately the same amount of labor as the CONV system. However, labor needs are distributed over time such that operator labor can be used to satisfy a larger proportion of labor needs. However, the AR/WC system requires considerably more labor than the CONV system.

Table 4.4. **Annual Operator Labor and Purchased Labor Hours, By System, for 500 Acre Representative Farm**

| System | Operator Labor | Purchased Labor |
|---|---|---|
| CONV | 827.90 | 288.50 |
| SPLN | 827.90 | 288.50 |
| WC | 823.95 | 541.45 |
| LWC | 880.95 | 430.70 |
| AR | 905.00 | 211.45 |
| AR/WC | 1011.70 | 334.35 |
| PL | 827.95 | 405.50 |

The PL system requires additional labor, as compared to the CONV system, for spreading the poultry litter. The additional labor is required at a time when operator labor constraints are binding, so that additional purchased labor is needed.

### *Nitrogen Residuals from Alternative Systems*

The loss of nitrogen residuals from each production system is presented in table 4.5. Per acre nitrogen residuals for each year and the total for the 10 year period are shown for each system. Each of the alternative production systems results in a lower level of nitrogen residuals than the CONV system.

The PL system results in the largest decrease in nitrogen residuals. As compared to the CONV system, nitrogen residuals are 35.5 percent lower over the 10 years with the PL system. The LWC system has the next lowest level of nitrogen residuals. With the LWC system, nitrogen residuals are 34 percent lower than for the CONV system. The reduced level of residuals for each

Table 4.5. **Residual Nitrogen, Per Acre, From Each Production System, Annual Levels and Total for Ten Years**

| | Production System | | | | | | |
|---|---|---|---|---|---|---|---|
| Year | CONV | SPLN | WC | LWC | AR | AR/WC | PL |
| 1 | 64.7 | 42.8 | 57.9 | 50.0 | 53.4 | 50.0 | 42.6 |
| 2 | 64.7 | 42.9 | 56.1 | 43.6 | 52.5 | 44.9 | 42.0 |
| 3 | 64.7 | 42.9 | 55.6 | 42.8 | 52.5 | 44.2 | 41.7 |
| 4 | 64.7 | 42.9 | 54.7 | 41.7 | 52.5 | 43.3 | 41.6 |
| 5 | 64.7 | 42.9 | 55.9 | 41.2 | 52.5 | 42.9 | 41.5 |
| 6 | 64.7 | 42.9 | 55.2 | 41.3 | 52.5 | 42.9 | 41.6 |
| 7 | 64.7 | 42.9 | 55.2 | 41.3 | 52.5 | 42.9 | 41.6 |
| 8 | 64.7 | 42.9 | 55.2 | 41.3 | 52.5 | 42.9 | 41.6 |
| 9 | 64.7 | 42.9 | 55.2 | 41.3 | 52.5 | 42.9 | 41.6 |
| 10 | 64.7 | 42.9 | 55.2 | 41.3 | 52.5 | 42.9 | 41.6 |
| Total | 647.0 | 428.9 | 556.2 | 425.8 | 525.9 | 439.8 | 417.4 |
| (index) | (100.0) | (66.3) | (86.0) | (65.8) | (81.3) | (68.0) | (64.5) |

of these systems reflects the use of organic nitrogen sources and the assumption that the decay of organic nitrogen occurs in tandem with plant needs. In later years, residuals are slightly lower for the LWC system than for the PL system. However, the 10 year total is slightly higher since, in early years, higher amounts of inorganic nitrogen fertilizer are needed by the LWC system.

The SPLN system has the next lower level of nitrogen residuals, 33.7 percent lower than the CONV system. Residuals are lower for the SPLN system since less nitrogen fertilizer is applied and more of the fertilizer applied is used by the crops. The AL/WC system has a slightly higher level of nitrogen residuals than the SPLN system. Residuals are higher in earlier years for the AR/WC system since a slightly larger amount of nitrogen fertilizer is required in the first year by the AR/WC system.

The AR system reduces nitrogen residuals by 18.7 percent as compared to the CONV system. The lower level of residuals from the AR system is due, primarily, to the reduced amount of nitrogen fertilizer used. Residuals from the WC system are 14 percent lower than from the CONV system. Residuals from the WC system are lower because of the role of the rye cover crop as a sink for some of the excess nitrogen remaining at the end of the cropping season.

### *Further Considerations*

The reduction of nitrogen residuals by the alternative production systems suggests that, from a water quality perspective, conversion to any of the alternatives would be preferable to continued use of the CONV system. The water quality policy issue becomes how to effectively encourage producers to adopt an alternative system. The profit maximization criteria for production decisions suggests that producers should voluntarily adopt the PL, SPLN or AR system if, in fact, transition costs do not significantly reduce the PVNR from the systems. However, there may be significant transition costs which are not accounted for by the analysis.

It is possible that increased labor requirements of the alternative production systems will inhibit their use by part-time farmers. In order to determine whether different constraints would impact the profitability of the alternative systems for part-time farmers, the model was adjusted to examine the systems under conditions specific to part-time farmers. The only changes to the model were the constraint coefficients for land and operator labor. Based on averages for the study area (again the farmer survey was used), a cropland constraint of 200 acres was used. Labor constraints were adjusted to account for a 40 hour off-farm work week. The part-time farmer labor constraints are:

March - 65.8 hours
April - 65.8 hours
May - 77.8 hours
June - 119.5 hours
September - 137.8 hours
October - 79.6 hours
November - 81.3 hours

The calculation of these constraints is shown in appendix A.

The model was again solved separately for each system. The results did not change the relative profitability of the alternative systems. The reduction in cropland acreage was sufficient to off-set the reduction in labor availability of a part-time producer. This suggests that, for those part-time farmers who operate farms which are smaller than those farms operated by full-time farmers, as was found in the study area, labor constraints will not limit the profitability of the alternative production systems considered.

There may be other constraints to the adoption of an alternative production system. An obvious example is the lack of availability of poultry litter in the study area as a source of nitrogen. Less obvious constraints may also exist, not the least of which is the use of some decision criteria other than profit maximization. A number of researchers have considered alternative approaches for explaining producers′ adoption decisions. One such perspective is presented in the following section.

# Section IV

## *The Adoption Model*

# Chapter 5

## *Farmers' Nitrogen Management Decisions: An Alternative Theory*

In the previous section, producers' nitrogen management decisions were examined in the context of economic theory of the firm. An empirical model was constructed to examine the relative profitability of alternative productions systems in order to predict a producer's choice of production system with its associated nitrogen management strategy. Underlying the economic analysis is the premise that, given the assumptions of perfect information, risk neutrality, and elastic input supply, the profit-maximizing producer will choose the technology for which the maximum profits attainable are the largest. However, there has been substantial disagreement over why farmers adopt or reject alternative technologies (Nowak), primarily because it is recognized that the assumptions underlying economic theory of the firm are not always valid. In this section, an alternative theory is presented which deals specifically with producers' decisions to adopt new technologies. The alternative production systems and the associated nitrogen management strategies are considered in the context of the alternative theory, and an empirical model is developed to examine farmers' conversion decisions from the alternative perspective.

### Alternative Nitrogen Management Systems - The Conversion Decision

Economic theory maintains that profit maximization is the objective of individual producers. A producer will adopt a new technology if it is more profitable than the technology currently in use. Numerous researchers have presented empirical evidence that the profitability of an alternative technology is the primary factor influencing its adoption (Griliches; Cancian; Miller). However, the profit maximization objective has been challenged, and research has suggested that farm operators actually have many, varying objectives which they seek to satisfy (Gasson). If a producer desires to produce a specific crop, minimize his own labor input, or minimize risk, he may consciously make production decisions which, in fact, do not maximize profits.

In addition, the proposition that firms operate with perfect information, including perfect knowledge of the probability of future events and prices and perfect information regarding all relevant production technologies and input choices, has been questioned (Cyert and March). It is widely recognized, in addition, that firms have differential access to and ability to use information (Nowak). In general, it is argued that information is not given to the firm but must be obtained, that alternatives are searched for and discovered sequentially, and that the order in which the environment is searched determines to a substantial extent the decision that will be made (March and Simon).

It is widely recognized, also, that risk neutrality of producers is an unrealistic assumption. Research has shown that, in general, farmers tend toward risk aversion, and decision analysis techniques have incorporated risk attitudes (Robison et al.; Young). A risk averse farmer may choose to continue using a conventional nitrogen management strategy since it is familiar and its uncertainties fairly well understood. Similarly, a risk averse producer may find an alternative legume-based nitrogen management system less profitable than the risk neutrality assumption suggests, since he may over-compensate for perceived risks by continuing to supplement organic nitrogen with commercial nitrogen at a higher rate than is necessary to meet crop requirements.

Finally, the assumption of a perfectly price elastic supply of inputs is seldom realistic. In particular, observers have pointed out the likely impacts on availability and price of organic nitrogen inputs, such as legume seeds, if a wide-scale conversion to alternative nitrogen management systems increases the demand for such inputs (Buttel et al.). Similarly, increased labor and management requirements with alternative systems may be difficult to satisfy, especially in the short run.

In light of these dissatisfactions with the approach of traditional economic theory for explaining farmers' decisions, psychologists, sociologists and agricultural economists have made use of an alternative theory - the theory of innovation diffusion and adoption - to provide a basis for examining farmers' decisions to adopt or reject new technologies.

The diffusionist perspective maintains that adoption behavior is primarily a function of exposure to information (Napier et al.). Profitability aside, adoption decisions depend upon whether farmers are aware of the need for a new technology, are able to obtain valid agronomic and economic information so as to evaluate the potential consequences, and receive assistance in transferring the technology while accounting for unique climatic, soil, managerial, and social conditions (Nowak). The application of the innovation diffusion and adoption model to agricultural technologies is not new. Researchers have examined the adoption of new crop varieties, fertilizers, machinery, and tillage practices from the perspective of the diffusion model (Brandner and Strauss; Beal and Rogers; Ervin and Ervin). Alternative nitrogen management strategies are yet another example of agricultural technologies to which the diffusion model can be applied.

### *Nitrogen Management Strategies as Innovations*

An issue which arises in applying the innovation diffusion model to the adoption of alternative nitrogen management strategies is whether such strategies can really be called innovations. According to Rogers and Shoemaker, an innovation is an idea, practice or object which is perceived as new by an individual. The alternative nitrogen management strategies considered in this study have been around for years. Livestock farmers commonly spread animal wastes on cropland. Before the advent of readily available, relatively inexpensive nitrogen fertilizers, using legume green manures to supply nitrogen was a common practice. It could be argued that these practices are common knowledge to farmers.

However, "new" in an innovative idea need not be simply new knowledge (Rogers and Shoemaker). An innovation might be known by an individual for some time (that is, he is aware of the idea), but he has not yet developed a favorable or unfavorable attitude toward it, nor has he adopted or rejected it. The "newness" of an innovation may be expressed in knowledge, in attitude, or regarding a decision to use it. In addition, there is more to the knowledge of an innovation than simply awareness of it. Also important as a basis for effective decision making about an innovation is the degree of knowledge about how properly to use the innovation, which is significant for nitrogen management.

## Innovation Diffusion and Adoption - A Theoretical Model

The innovation diffusion model as developed by Rogers and Shoemaker presents the innovation adoption decision as a process, the outcome of which depends upon characteristics of the innovation, characteristics of the potential adopters, and the communication of information from change agents to the potential adopters.[5] The four stages of the innovation diffusion process include:
1) **Knowledge** - the individual is exposed to the innovation's existence and gains some understanding of how it functions. There are different types of knowledge. One is awareness that an innovation exists, either from looking for it or from happening upon it. "How-to" knowledge is the information necessary to use an innovation properly. Principles knowledge refers to knowledge of the principles underlying an innovation, such as an understanding of the principles of plant growth when considering the use of nitrogen fertilizers.
2) **Persuasion** - the individual forms a favorable or unfavorable attitude toward the innovation. An attitude is a relatively enduring organization of an individual's beliefs about an object that predisposes his actions. An individual may hold a specific attitude toward the innovation or a general attitude toward change which can affect his adoption decision. Innovation dissonance is the discrepancy between an individual's attitude toward an innovation and his decision to adopt or reject the innovation. Theory suggests that there is pressure in the direction of dissonance reduction.
3) **Decision** - the individual engages in activities which lead to the choice to adopt or reject the innovation.

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[5] Rogers defines a change agent as an individual who influences clients' innovation decisions in a direction deemed desirable by a change agency (or resource system).

4) **Confirmation** - the individual seeks reinforcement from the decision he has made and may reverse his decision if he receives conflicting information.

How quickly the process of innovation adoption proceeds depends, in part, on the innovation itself. Significantly, it is the receivers' perception of the attributes of innovations, not the attributes as classified by experts or change agents, which affect their rate of adoption (Rogers and Shoemaker). There are five primary characteristics of innovations which contribute to the rate of adoption.

The first is the relative advantage, or the degree to which an innovation is perceived as better than the idea it supersedes. The degree of relative advantage may be measured in economic terms, but often social prestige factors, convenience, and satisfaction are also important components. A greater perceived relative advantage results in a more rapid rate of adoption.

Relative profitability may be one indication of the advantage of an alternative production system. The results of the economic analysis in the previous section present an indication of the relative profitability of the seven alternative production systems considered in this study. However, the diffusionist perspective maintains that other factors may be equally or more important in determining relative advantage (Havens and Rogers; Dixon).

Environmental impact of alternative production systems is another measure of relative advantage. Producers who are particularly concerned about the environmental impacts of their production activities may perceive advantages to nitrogen management strategies which minimize environmental costs. Specifically, the leaching of nitrates into groundwater is of concern to producers whose families depend upon groundwater for drinking water. In Virginia, 28 percent of the population relies on private wells for drinking water, and the coastal plain region of Virginia accounts for over half of total groundwater consumption in the state (Virginia Water Control Board). The surface runoff of nitrogen and the contributions of return flows from ground water into surface water also may be an important consideration for producers who place a high value on water quality in the Chesapeake Bay and its tributaries.

The relative riskiness of alternative production systems may also be viewed as an indication of relative advantage. A risk averse producer will view as relatively more advantageous an alternative system which reduces the variability of crop yields, which increases the likelihood of applied nitrogen fertilizer being used by the crop, or which assure that crop nitrogen requirements will be met. However, new technologies may be viewed as more risky because of the inherent uncertainties associated with changing technologies.

A second characteristic of innovations is compatibility, the degree to which an innovation is perceived as consistent with the existing values, past experiences and needs of the receiver. A more compatible innovation will be adopted quicker. The compatibility of an alternative nitrogen management strategy will depend, in part, on how it can be adapted to current operations, such as crop rotation, equipment availability, and the availability of inputs. If the producer neither perceives a need for a change nor perceives alternatives as compatible with his current operation, he is less likely to adopt an alternative system. Specifically, if alternative systems require management or labor inputs which are not available, they will not be compatible with existing production constraints. Similarly, compatibility with specific goals or values held by the producer will influence the acceptability of alternative systems. The desire to grow specific crops, or produce them in a specific manner, may preclude the use of some alternative nitrogen management strategies.

Complexity is a third characteristic of innovations and refers to the degree to which an innovation is perceived as difficult to understand and use. The complexity of an alternative production system is a function of the amount of new information needed to successfully implement the system, the changes required in management skills and management styles, and the changes required in equipment or other aspects of the production operation. Generally, those new ideas requiring little additional learning investment on the part of the receiver will be adopted more rapidly than innovations requiring the adopter to develop new skills and understandings. Conversion to an alternative nitrogen management system generally represents a move from a relatively simple to a more complex system. The complexity arises from the additional planning, management expertise and information required.

Trialability, a fourth characteristic, refers to the degree to which an innovation may be experimented with on a limited basis. New ideas which can be tried on the installment plan will generally be more quickly adopted than those which are not divisible. Essentially, trialability represents less risk to the person considering the innovation. Nitrogen management strategies can generally be tried on a small scale and evaluated by producers before they are adopted. However, while organic nitrogen sources can be tried on a small acreage, considerable time may be required to observe the results of the build-up of organic nitrogen and properly evaluate the results. Finally, observability is the degree to which the results of an innovation are visible to others. The rate of adoption will be faster when potential adopters are able to observe the consequences of adoption. In general, the observability of alternative nitrogen management systems will be limited. Viewing crop stands will not inform the viewer as to the source of nitrogen used. However, demonstrations have been used to give producers exposure to alternative systems and to substitute for a producer's own trial of alternatives (Magill and Rogers). Also, the returns a producer realizes from a particular system will not be common knowledge. Nevertheless, successful technologies are generally a common topic of conversation between farm operators.

The adoption process is also influenced by the relative innovativeness of the adopter. Rogers and Shoemaker recognize five adopter categories. These are: innovators, early adopters, early majority, late majority, and laggards. Based on studies of adoption and adopters, researchers have determined that specific adopter characteristics are associated with the relative innovativeness of adopters. These include socioeconomic characteristics, personality characteristics, and communication behavior. Each of these characteristics reflects, in part, adopters' objectives; their access to and ability to use information on alternative technologies; their attitudes toward risk; and their need for and access to additional inputs such as labor. A number of adopter characteristics can be identified which are likely to impact, in particular, the adoption of alternative nitrogen management strategies.

**Socioeconomic Characteristics** - A producer who can be characterized by certain socioeconomic factors may be more likely to adopt an alternative nitrogen management strategy. These factors include farm size, education level, whether the producer is a part- or full-time farmer, and planning horizon. Although there is no reason to expect scale effects associated with alternative nitrogen management strategies, access to additional labor and capital may be associated with larger farm size. If an alternative nitrogen management strategy requires additional labor or capital, then operators of larger farms may be be more likely to adopt the alternative system. In addition, operators of larger farms may be in a better position to try the new technology on a small acreage without significantly impacting the total operation.

Farmers with higher education might be expected to adopt alternative nitrogen management strategies more quickly since they are more likely to recognize the benefits of alternative systems and to understand and use technologies such as manure and tissue testing. In general, farmers with higher education possess higher allocative ability, the ability to adjust to change, and adjust more quickly to changes in technology by adopting new production practices (Huffman).

Full-time farmers have been found to adopt alternative technologies more readily than part-time farmers (Norris and Batie). A full-time, commercial operator is more likely to invest the time required to learn about a new nitrogen management system. Part- time farmers will generally have less time to devote to the farm operation and the consideration of alternative production systems.

The planning horizon of the producer will also influence his decision to use an alternative nitrogen management system. A producer who plans to discontinue his operation in the near future will be less likely to invest in learning about alternative systems. Similarly, producers with shorter planning horizons will likely place less value on maintaining or improving the long term productivity of the soil and profitability of the operation. Thus, they will be less interested in the long run benefits of a system which, for example, incorporates organic sources of nitrogen, especially if it is not clear that such benefits will be realized in the market value of the land.

**Personality Characteristics** - Research has suggested that early adopters have more favorable attitudes toward change and its associated uncertainties. Those farmers who are averse to making changes in their production operation will be less likely to adopt an alternative nitrogen management strategy. Early adopters tend to have a more favorable attitude toward science (Rogers and Shoemaker). It has also been suggested that early adopters are better able to deal with abstractions. This suggests that early adopters of alternative nitrogen management systems will be those who have a better understanding of the intricacies and uncertainties of the movement of nitrogen within the soil. Later adopters will be less influenced by abstract and scientific information and will be more interested in the proven physical and economic results of a conversion to an alternative system.

**Communication Behavior** - The communication behavior of potential adopters involves their exposure to information sources. Early adopters tend to have more social interaction and a greater exposure to mass communication and personal communication channels. Thus, it takes less effort to obtain information on new technologies. Producers who actively communicate with a larger group of information sources should be more likely to learn of alternative nitrogen management strategies.

Evidence also suggests that those farmers who have more contact with change agents and who actively seek information on innovations tend to adopt new technologies more quickly. Later adopters will be less likely to seek information. This suggests that producers who actively pursue information on nitrogen management will be more likely to adopt a new nitrogen management strategy.

## The Adoption of Nitrogen Management Strategies

The innovation diffusion and adoption model, as applied to nitrogen management decisions, expresses a producer's choice of a nitrogen management system as a function of characteristics of the system and characteristics of the producer himself. Based on the theoretical model, an empirical model can be constructed to observe the impact of specific producer and system characteristics on a producer's decision to adopt a particular nitrogen management strategy. As discussed previously, the conventional production system in the study area involves a single application of inorganic nitrogen fertilizer at the time the crop is planted. Two specific alternative strategies which are also being used by some producers in the study area include: 1) splitting nitrogen applications and 2) using winter annual legumes as green manures. The adoption of each of these alternative strategies can be modeled according to the theoretical model presented above.

In order to examine producers' adoption of these alternative nitrogen management strategies, a survey of farmers in the study area was conducted. The survey consisted of three main types of questions. First, a set of questions was included to obtain demographic information for the sample. Second, questions were included to obtain information on the sample producers' production practices. Finally, a series of questions was included to ask producers' opinions about and attitudes toward a number of issues and production practices related to nitrogen management.

Models of producers' adoption of the split nitrogen application and legume green manure systems were specified according to the adoption and diffusion model. Data from the survey was used to define the model variables and empirically estimate the impact of producer and system characteristics on the adoption decision. The following discussion presents the empirical models and definitions of the model variables and the hypotheses generated. Measurement of the individual variables identified will be discussed in the following chapter.

## *Adoption of the Split Nitrogen Application System*

The empirical adoption model for the split nitrogen application system was specified as:

$$SPLITN = f(SPRA1, SPRA2, COMP, CPXSPL, SIZE, EDUC1, EDUC2, \\ EDUC3, EDUC4, FP, ENVIR, CHANGE, INFO, COMMUN), \qquad [5.1]$$

where $SPLITN$ represents the producer's decision to adopt the split nitrogen system.

$SPRA1$ and $SPRA2$ represent the producer's perception of the relative advantage of the split nitrogen system. $SPRA1$ indicates how strongly the producer believes that the split nitrogen application system is too costly and time consuming. A negative relationship between $SPLITN$ and $SPRA1$ is hypothesized. $SPRA2$ indicates how strongly the producer believes the split nitrogen application system reduces the amount of nitrogen that will be lost from the field during a rain storm, and a positive relationship between $SPLITN$ and $SPRA2$ is hypothesized.

$COMP$ is a measure of the producer's perception of the compatibility of the split nitrogen system with his current operation. Producers are more likely to adopt the split nitrogen system if they view it as compatible with their current production system. $CPXSPL$ represents the complexity of the split nitrogen system as determined by the producer's indication of how much information he currently has about the system. For producers with more information, the system will be less complex. Therefore, a positive relationship between *CPXSPL* and *SPLITN* is expected.

*SIZE* equals the total number of cropland acres operated by the producer, and a positive relationship to adoption is hypothesized. *FP* is a dummy variable indicating whether the producer is a full time farmer. Full-time farmers are hypothesized to be more likely to adopt a split nitrogen application system than part-time farmers. *EDUC*1 through *EDUC*4 are dummy variables included to represent the producer's level of education. Producers with higher levels of education are hypothesized to be more likely to adopt a split nitrogen application system than producers who have fewer years of formal education.

*CHANGE* represents the producer's attitude toward and propensity to change. Producers who are more positive toward change and perceive a need for change in their production systems are hypothesized to be more likely to adopt the split nitrogen system. *ENVIR* is a measure of the producer's concern about the impacts of agricultural production. The relationship between *ENVIR* and *SPLITN* is also expected to be positive.

*COMMUN* indicates the amount of contact the producer has with sources of information on nitrogen application. A positive relationship between *COMMUN* and *SPLITN* is hypothesized. *INFO* represents how actively the producer seeks additional information on nitrogen management. Producers who actively seek additional information are hypothesized to be more likely to adopt a split nitrogen application system than producers who do not seek such information.

### *Adoption of the Legume Green Manure System*

The legume green manure adoption model was specified as:

$$LEGN = f(LGRA1, LGRA2, COMP, CPXLEG, SIZE, EDUC1, EDUC2, \qquad [5.2]$$
$$EDUC3, EDUC4, FP, PLAN, ENVIR, CHANGE, INFO, COMMUN),$$

where *LEGN* represents the decision to adopt a legume green manure system.

*LGRA*1 and *LGRA*2 represent the producer's perception of the relative advantage of the legume green manure system. *LGRA*1 indicates how strongly the producer believes that the legume green manure system is too costly and time consuming. A negative relationship between *LEGN* and *LGRA*1 is hypothesized. *LGRA*2 indicates how strongly the producer believes the legume green manure system reduces the amount of nitrogen that will be lost from the field during a rain storm, and a positive relationship between *LEGN* and *LGRA*2 is hypothesized.

*COMP* is a measure of the producer's perception of the compatibility of the legume green manure system with his current operation. Producers are more likely to adopt the legume green manure system if they perceive it to be compatible with their current system. *CPXLEG* represents the complexity of the legume green manure system. Again, a higher value for *CPXLEG* indicates that a producer has more knowledge of the system and so the system will be less complex. Therefore, a positive relationship between *CPXLEG* and *LEGN* is expected.

*SIZE*, *FP*, and *EDUC*1 through *EDUC*4 are defined in the same way that they are defined for the *SPLITN* model and their hypothesized impact on *LEGN* is the same. An additional variable is included to describe the producer. *PLAN* is a dummy variable included to indicate whether the producer expects to continue farming for the next ten years. Producers with a longer planning horizon are expected to be more likely to adopt a legume green manure system.

The *CHANGE*, *ENVIR*, *COMMUN* and *INFO* variables all have the same value as in the *SPLITN* model and the hypothesized relationships with *LEGN* are the same.

## Summary

This chapter presented adoption models for two specific nitrogen management strategies, the specification of which was based on the theory of innovation and adoption. The model variables were obtained from data from a farmer survey. For each strategy, adoption is modeled as a function of producer characteristics and producer perception of the characteristics of the strategy. In the following chapter, the data collection, measurement of variables, and estimation techniques used in the estimation of these empirical models are discussed.

# Chapter 6

## Estimation of Adoption Models - Procedures and Results

### Data

As stated, the data for the estimation of the empirical adoption models specified in the previous chapter was obtained through a survey of farmers. A mail survey was used, and a sample of farmers from Westmoreland and Richmond counties in the Northern Neck and Essex county in the Middle Peninsula was chosen to participate in the survey. These three counties were chosen because they are fairly representative of the entire region, in terms of agricultural activities, and because previous research conducted in the area facilitated the selection of the survey sample.

A sample of 1127 names was chosen from lists of farm owners and operators maintained by the Agricultural Stabilization and Conservation Service (ASCS) county offices. The sample drawn represented the entire list from each county less the names drawn for an earlier survey (Ligon et al.). Those persons who were included in the earlier sample were excluded from the sample for this study to avoid alienating producers who received the earlier survey.

The survey was administered according to Dillman's method. Each producer on the list received a copy of the survey tool, accompanied by a letter explaining the survey and a business reply envelope. A follow-up reminder card was mailed one week after the initial mailing of the survey. A second copy of the survey, with a second letter, was mailed three weeks after initial mailing to those producers who had not yet responded.[6] Copies of the survey tool, cover letters, and reminder card are in Appendix C.

All recipients of the survey were asked to return the questionnaire; those in the sample who were not farming were asked to return the blank survey form. Of the 1127 persons in the initial sample, 67 were deceased or had moved and could not be located. Of the remaining 1060, 572 returned survey forms. Of those, 112 surveys were completed and useable. The remainder were returned blank by persons not actively farming or were returned incomplete. Thus, the final sample consisted of 112 producers.

## *Demographics of the Sample*

The average age of the sample farmers is 53 years.[7] This compares to an average age of 54 for farmers in the 11 county study area (United States Department of Commerce). Seventy- one percent of the producers had completed high school; 21 percent were college graduates. Sixty-two percent of the respondents reported having spent more than 20 years farming.

Almost 42 percent of the sample farmers were full time farmers. Another 31 percent reported working full time off the farm. Average farm size for the sample, calculated as the sum of owned and rented acreage, was 486 acres. This compares to an average of 258 acres for the 11 county study area (United States Department of Commerce). Average number of acres owned was 238, while an average of 248 acres was rented. Averaged across respondents, 43 percent of total household income comes from the farm operation in an average year. Seventy percent of the respondents expected to continue farming for the next ten years.

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[6] The Dillman method includes mailing surveys a third time. However, a third mailing was not made for this study since it would have reached farmers well into the planting season. It was deemed that such a mailing would not increase the response rate substantially.

[7] In some cases, not all 112 farmers in the sample responded to a particular question. Averages and percentages are calculated for each question based on the number of producers responding to that question.

## Measurement of Model Variables

### *The SPLITN Model*

As presented in the previous chapter, the adoption model for the split nitrogen application system was specified as:

$$SPLITN = f(SPRA1, SPRA2, COMP, CPXSPL, SIZE, EDUC1, EDUC2, EDUC3, EDUC4, FP, ENVIR, CHANGE, INFO, COMMUN). \qquad [6.1]$$

The survey data was used to measure each of the model variables. The dependent variable, *SPLITN* is defined as 1 if the producer uses a split nitrogen application system, 0 if he does not. The split nitrogen system was described to the producers as:

> In a corn, wheat, soybean rotation, nitrogen fertilizer is applied to corn in two separate applications. 25 lbs/acre of nitrogen is applied at planting. Then 110 lbs/acre is applied 25-30 days after the corn emerges.

Producers were asked whether they currently use two separate applications of nitrogen for corn.

*SPRA1* is measured by the producer's response to the statement:

> Splitting nitrogen into two separate applications is too costly and time consuming.

*SPRA1* takes on a value of 4 (strongly agree), 3, 2, or 1 (strongly disagree) to indicate how strongly the producer agrees with the statement. *SPRA2* also takes on a value of 4, 3, 2, or 1 to indicate how strongly the producer agrees with the statement:

> Splitting nitrogen applications reduces the amount of nitrogen that will be lost from the field during a rain storm.

Since the system was described for corn production, *COMP* is included as a dummy variable equal to 1 if the producer is growing corn, 0 if he is not. Producers who grow corn are expected to be more likely to adopt the split nitrogen system.

*CPXSPL*, complexity of the system, is measured by the producer's indication of how much information he currently has about the system. For the split nitrogen system, *CPXSPL* takes on the value 4, 3, 2, or 1 to indicate how strongly the producer agrees with the statement:

> Splitting nitrogen applications reduces the total amount of nitrogen fertilizer required.

*SIZE* is a continuous variable measured as the total number of cropland acres operated by the producer. *FP* is a dummy variable equal to one if the producer is a full time farmer, 0 if he is not. *EDUC*1 through *EDUC*4 are dummy variables defined as:

*EDUC*1 = 1 if the producer completed high school, 0 otherwise;
*EDUC*2 = 1 if the producer completed some college, 0 otherwise;
*EDUC*3 = 1 if the producer completed college, 0 otherwise;
*EDUC*4 = 1 if the producer completed some graduate education or obtained a graduate degree, 0 otherwise;

The reference category contains those producers who completed the 11th grade or less.

The *CHANGE* variable is measured by the producer's response to statements about changes in the farm operation. The producers were presented with the following statements:

> Insect problems seem to be increasing with my current production system;
>
> Weed problems seem to be increasing with my current production system;
>
> My current production system depends too much on fuel, fertilizers, and pesticides which may become scarce or too expensive.

The *CHANGE* variable is calculated as the linear summation of the responses to each statement. Each statement was assumed to reflect, equally, producers' receptivity to change and was weighted equally. Since the response to each of these statements can take on a value of 1 to 4, the *CHANGE* variable takes on a value of 3 to 12.

The questionnaire included five statements regarding the need for change in current production systems. Producers' responses to the other two statements:

> I should increase the number of crops I plant in order to be less dependent on just a few crops
>
> My current rotation and fertilizer practices are reducing the productivity of the soil

were not included in the change variable. A disjoint cluster analysis (SAS Institute, Inc.) was used to examine producers' responses to the five statements. Clusters were created for all five statements, for the three statements used, and for the two statements above. Clustering according to the three statements used to define the *CHANGE* variable placed observations into clusters differently than when all five statements or just the two statements above were used. Also, there was very little variation across producers in the responses to the two statements above.[8]

*ENVIR* is calculated as the sum of the producer's response to the statements:

The loss of chemicals from cropland is an important cause of water pollution.

Pesticides used on the farm may pose health risks for humans and animals.

Again, a linear summation of responses was used. The response to each of these statements can take on a value of 1 to 4, so the *ENVIR* variable can take on a value of 2 to 8.

*COMMUN* is calculated as the number of different sources the producer consults in making nitrogen application decisions. Possible sources of information include extension recommendations, Virginia Tech soil tests, commercial soil tests, fertilizer dealer recommendations, and an other category. *INFO* equals 1 if the producer requested, on the survey form, additional information on nitrogen sources, 0 if he did not.

## *The LEGN Model*

Again, the legume green manure adoption model was specified as:

$$LEGN = f(LGRA1, LGRA2, COMP, CPXLEG, SIZE, EDUC1, EDUC2, EDUC3, \quad [6.2]$$

$$EDUC4, FP, PLAN, ENVIR, CHANGE, INFO, COMMUN),$$

where *LEGN* equals 1 if the producer uses a legume green manure to provide nitrogen for corn, 0 if he does not. The legume green manure system was described as:

> In a corn, wheat, soybean rotation, a nitrogen-fixing legume is overseeded into soybeans before the soybeans are harvested. In the spring, the legume is disked under and corn is planted.

The producers were asked whether they currently use a legume as a green manure to provide nitrogen for corn.

*LGRA1* takes on a value of 4 (strongly agree), 3, 2, or 1 (strongly disagree) to indicate how strongly the producer agrees with the statement:

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[8] Cluster analysis groups observations into clusters suggested by the data, so that objects in a given cluster tend to be similar to each other in some sense, and objects in different clusters tend to be dissimilar.

> Using legume cover crops is too costly and time consuming.

*LGRA2* also takes on a value of 4, 3, 2, or 1 to indicate how strongly the producer agrees with the statement:

> Nitrogen from legumes is less likely than fertilizer nitrogen to be lost from the field during a rain storm.

The *COMP* variable is included as a dummy variable equal to 1 if the producer is growing corn, 0 if he is not.

For the legume system, *CPXLEG* is calculated as the sum of the producer's responses to questions asking how strongly he agrees with the statements:

> The legume can supply most of the nitrogen for the corn crop.
>
> Some of the nitrogen from the legume would still be left for the wheat crop.

Again, a linear summation of responses was used. Since the response to each of these statements can take on the value 4, 3, 2, or 1, the *CPXLEG* variable takes on a value of 2 to 8. Again, a cluster analysis was conducted, and these two statements were chosen, excluding a third survey statement about information to measure the *CPXLEG* variable. The third statement:

> Legumes will improve a soil's physical properties,

was excluded since there was very little variability across producers in their responses to the statement.

*SIZE*, *FP*, and *EDUC*1 through *EDUC*4 are measured in the same way that they are measured for the *SPLITN* model. The *PLAN* variable equals 1 if the producer expects to continue farming for the next ten years, 0 if he does not. The *CHANGE*, *ENVIR*, *COMMUN*, and *INFO* variables all have the same value as in the *SPLITN* model.

## Estimation Technique

The adoption models are specified as qualitative choice models. In general, the qualitative choice model determines the relationship between a set of attributes describing an individual and the probability that the individual will make a given choice (Pyndyck and Rubenfeld). For example, the probability that a producer will choose to use a split nitrogen technique, given a set of characteristics - specifically personal characteristics and perceptions of technique characteristics - can be estimated using the *SPLITN* model. Similarly, the second model can be used to estimate the probability that an individual having certain attributes will choose to adopt a legume green manure system.

Because of the dichotomous nature of the dependent variables in qualitative choice models (i.e. having a value of 0 or 1), ordinary least squares (OLS) is not appropriate as an estimation technique. Standard OLS estimation of the linear probability model results in three specific problems. First, the variance of the error term is heteroscedastic. Second, the disturbance term is not normally distributed, and so the classical statistical tests of significance are not applicable. Finally, and perhaps most importantly, the linear probability model yields predicted values of the probability of adoption which lie outside the interval between 0 and 1, which is inconsistent with the definition of probability.

To avoid these problems associated with applying OLS to binary choice models, the LOGIT analysis technique was used. The LOGIT model monotonically transforms the standard linear probability model using the cumulative logistic probability function. The transformation assures that predicted probabilities lie within the unit interval. Maximum likelihood estimation of the LOGIT model assures the consistency and normality of the parameters so that conventional test of significance are applicable. The SHAZAM econometrics package was used to perform the maximum likelihood estimation (White and Horsman).

## *Scope of the Analysis*

The theory of innovation diffusion and adoption presents the adoption of an innovation as a process which occurs over a period of time. The use of the LOGIT technique accounts only for whether a producer is using a particular method. The technique has nothing to say about how long the producer has been using the method or whether he will continue to use it. Nor do the independent variables used in the empirical models examine the producer's status in the adoption process.

# Results

## *The Split Nitrogen Application Model*

The results of the estimation of the *SPLITN* adoption model are presented in table 6.1. Because specific signs were hypothesized for each coefficient, one-tailed tests were used to test the significance of the estimated coefficients. A number of producer and system characteristics were found to significantly influence the decision to adopt a split nitrogen application system.

At the .10 level of significance, relative advantage and compatibility are the characteristics of the system which significantly impact the adoption decision. Farm size, the operator's communication with information sources, and whether the operator actively seeks information on nitrogen management also significantly impact the decision to use a split nitrogen application system. Using the likelihood ratio test, which is analogous to the F test in standard OLS regression, the null hypothesis that all coefficients are equal to zero is rejected at the .01 level. The model correctly predicts the adoption decision for 83 percent of the observations.[9]

### Interpreting the Results

Using the LOGIT estimation technique, the estimated coefficients do not indicate the change in the probability of adoption given a one unit change in the corresponding independent variable. Rather, the coefficients indicate the effect of a change in an independent variable upon the log of the odds of adoption. The sign of the coefficient does indicate the direction of the change (Judge

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[9] A correct prediction occurs when the predicted value of the probability of adoption for an individual who uses the system is greater than or equal to 0.5 and when the predicted value of the probability of adoption for an individual who does not use the system is less than 0.5.

Table 6.1. Results of LOGIT Estimation of the SPLITN Model

| Variable | Coefficient | t-ratio | Change in Probability |
|---|---|---|---|
| SPRA1 | -1.256 | -3.296 | |
| SPRA2 | .2010 | .5131 | |
| CPXSPL | .1629 | .4139 | |
| ENVIR | .0682 | .4125 | |
| CHANGE | -.0277 | -.1823 | |
| COMP | 2.231 | 1.681 | 2.026 |
| SIZE | .0009 | 1.368 | .0008 |
| EDUC1 | .4929 | .6481 | .4477 |
| EDUC2 | -1.211 | -1.056 | -1.100 |
| EDUC3 | .0170 | .0145 | .0154 |
| EDUC4 | 26.92 | .0002 | 24.45 |
| FP | .1535 | .2223 | .1394 |
| COMMUN | .8336 | 1.555 | .7571 |
| INFO | .9137 | 1.303 | .8298 |
| Constant | -2.509 | | |

N = 83
Likelihood ratio = 45.92, 14 d.f.
t($\alpha$ = .10, one-tailed) = 1.295
Z = 2.292

et al.). The impact of a change in a independent variable on the probability of adoption can be calculated, however.[10]

In table 6.1, the variables which are measured using the scale of 1 to 4 (or as a summation of 1 to 4 scales) are presented first. For these variables, the the changes in probability are not calculated. Since the scale variables are neither continuous nor binary, the resulting values can not be interpreted as the change in probability resulting from a one unit change (as for a continuous variable) or resulting from a particular characteristic of the observation (as for a binary variable). For the non-scale variables, the changes in probability are presented in the last column of the table.[11]

Relative advantage, as measured by the perception of costliness of the system, has a negative impact on the likelihood of adoption, as hypothesized. Also as hypothesized, compatibility of the system positively impacts adoption. Producers who grow corn are .85 percent more likely to adoption the split nitrogen system than producers who do not grow corn.

As expected, producers with some graduate level education are more likely to adopt the split nitrogen system than producers who have not graduated from high school (the reference category). Having some graduate education increases the probability of adoption by 1.7 percent. The impact of farm size on adoption also agrees with the stated hypothesis. An increase in cropland acreage of one acre increases by .0004 percent the probability of adoption of the split nitrogen application system. Finally, as hypothesized, producers′ communication behavior positively impacts adoption; an increase of one in the number of information sources contacted increases the probability of adoption by .2895 percent.

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[10] $\frac{\delta P_i}{\delta X_i} = f(Z_i)\beta$ where $f$ is the pdf associated with the logistic density function, and $Z_i = X_i'\beta$ , calculated at the means of the $X_i$ (Pyndyck and Rubenfeld).

[11] The magnitudes of the calculated probabilities, which are quite small, depend upon $f(Z_i)$, which in turn depends upon the initial values of the independent variables and their coefficients, and which reflects the steepness of the cumulative density function (CDF) at $X_i'\beta$. The steeper the CDF the greater the impact of a change in the value of an explanatory variable will be (Judge et al.).

### *The Legume Green Manure Model*

Results of the LOGIT estimation of the *LEGN* model are presented in table 6.2. At the .10 level of significance, relative advantage and complexity are the system characteristics which significantly impact adoption. The producer characteristics which impact adoption of the legume green manure system include education level, cropland acreage, whether the producer is a full-time farmer, planning horizon, communication behavior, information seeking activity, receptivity to change, and concern over the environmental impacts of agricultural activity. The likelihood ratio is significant at the .01 level. The model correctly predicts the adoption decision for 97 percent of the observations.

#### Interpreting the Results

Again, the scale variables are presented first in table 6.2. Relative advantage, as measured by the perception of costliness of the system, negatively impacts adoption of the system, as hypothesized. Complexity of the system, as measured by the producers′ level of information about the system, positively impacts the adoption decision, as expected.

With one exception, the coefficients of the producer characteristics which significantly impact the adoption decision have the hypothesized sign. Producers who have completed college are more likely to adopt the legume green manure system than producers who did not complete high school. Also, operators of larger farms and full-time operators are more likely to adopt the system. Producers who are more receptive to changes in their production systems are more likely to use a legume green manure, as are producers who agree that agricultural production practices may adversely affect the environment. Those proudcers who communicate with a larger number of potential sources of information on nitrogen management, and those who actively seek information on nitrogen management, are also more likely to adopt the legume green manure system. Finally, contrary to the stated hypothesis, planning horizon of the operator negatively impacts the adoption decision. Those producers who expect to continue farming for atleast the next ten years are less likely to adopt than those with a shorter planning horizon.

**Table 6.2. Results of LOGIT Estimation of the LEGN Model**

| Variable | Coefficient | t-ratio |
|---|---|---|
| LGRA1 | -20.44 | -2.048 |
| LGRA2 | -.5522 | -.4094 |
| CPXLEG | 2.423 | 1.920 |
| ENVIR | 3.779 | 1.966 |
| CHANGE | 2.379 | 1.711 |
| COMP | 8.458 | 1.246 |
| SIZE | .0087 | 2.155 |
| EDUC1 | -4.132 | -1.244 |
| EDUC2 | -2.058 | -.6808 |
| EDUC3 | 8.347 | 1.234 |
| EDUC4 | 14.54 | 1.860 |
| FP | 5.265 | 1.446 |
| PLAN | -7.504 | -1.895 |
| COMMUN | 4.013 | 1.858 |
| INFO | 15.49 | 1.979 |
| Constant | -37.69 | |

$N = 77$
Likelihood ratio = 61.56, 15 d.f.
$t(\alpha = .10$, one-tailed$) = 1.296$
$Z = -15.14$

Changes in probability were calculated for the non-scale variables presented in table 6.2. However, they are not reported because they are so small ( < .0001) and thus do not add to interpretation of the results. The magnitudes of the calculated changes in probability reflect the large number of observations (61) with a zero dependent variable - non-adopters. The changes in probability of adoption are very small because, at the means of the variables, the relevent portion of the CDF is flat (before the inflection point) indicating a low probability of adoption for the sample as a whole.

## Summary

The results suggest that, based on the significant impact of the perception of costliness on the adoption of the split nitrogen and green manure systems, financial considerations are important in producers′ adoption decisions. The importance of the compatibility and complexity of the split nitrogen and green manures systems, respectively, point out that transition and information costs may also be important considerations as farmers contemplate adoption of these systems. However, a number of producer characteristics also significantly influence adoption decisions. These results suggest that factors in addition to the relative profitability of alternative systems are important determinants of adoption behavior.

# Section V

## *Policy Considerations and Conclusions*

# Chapter 7

# *Policy Issues in the Adoption of Alternative Nitrogen Management Strategies*

Results of the optimization model presented in chapter four show six production systems which, by incorporating alternative strategies for managing nitrogen, could be expected to reduce nitrogen residuals from crop production. Given as a water quality goal in Virginia, and in the Chesapeake Bay drainage in particular, the reduction of nitrogen entering surface and ground water, encouraging producers' conversion to alternative production systems and nitrogen management strategies is an important policy consideration. Designing a water quality policy for influencing producers' nitrogen management decisions requires explicit recognition of the institutional setting in which a particular policy will be administered and of the likely impact of the policy on producers' decisions.

## The Policy Setting

Agricultural nonpoint pollution has received explicit attention from policymakers since the 1972 amendment of the Federal Water Pollution Control Act. The amendments required states to develop plans to identify critical nonpoint pollution problem areas, to select suitable best management practices (BMPs) to reduce pollution, and to designate management agencies responsible for nonpoint pollution control planning and implementation. The goal of agricultural nonpoint pollution control activities has been the reduction of sediment, nutrients and agricultural chemicals entering surface water from agricultural production activities.

In the Chesapeake Bay drainage area, pollution control efforts have been particularly intensive. Concern over the general health of the Bay, and the impacts of agricultural pollution on the Bay, has prompted actions at all levels of government to reduce the runoff of agricultural sediment and chemicals into the Bay and its tributaries. Specifically, in Virginia, a number of agencies and water quality programs have been involved in pollution control activities.

### *Institutions*

Currently, there are two primary policy initiatives which prescribe nonpoint pollution control efforts in Virginia. The first is the Clean Water Act of 1987 (CWA). The CWA specifically mandates that the state submit to the U.S. Environmental Protection Agency (EPA) a plan for controlling nonpoint pollution. The state has four years from its submission to implement the plan, assuming it is approved by EPA (Hansen et al.).

The second major policy initiative is the Chesapeake Bay Agreement (CBA) signed in 1987 by the governors of Virginia, Maryland, Pennsylvania, the Mayor of Washington, D.C., and the administrator of EPA. The agreement represents a commitment on the part of all jurisdictions and the federal government to reverse the degradation of the Bay and prevent further damage (Water News).

At the federal level, EPA is responsible for approving and overseeing the planning and implementation of nonpoint pollution control programs developed by the states. In addition, USDA has been designated as the federal department responsible for assisting states in carrying out their nonpoint pollution control plans. The traditional responsibilities of the USDA agencies, including technical assistance from the Soil Conservation Service (SCS), financial assistance from the Agricultural Stabilization and Conservation Service (ASCS) and information and education programs from the Cooperative Extension Service (CES) are to be made available to the states for assistance in implementing pollution control programs. Similarly, the federal involvement in the CBA makes these resources available to states in meeting the goals outlined in the agreement.

At the state level, responsibility for agricultural nonpoint pollution control falls to the Division of Soil and Water Conservation. As a result of the CWA and CBA, the Division has made an assessment of nonpoint problems in the state and developed a comprehensive plan for reducing agricultural nonpoint pollution (DSWC). In its Nonpoint Source Pollution Management Plan for agriculture, the ultimate goal of the program is stated as the reduction of "off-site water quality impacts of agricultural activities to an environmentally non-significant level while still maintaining soil productivity levels and economically feasible farm operations." The DSWC relies principally on a specified set of BMPs for reducing agricultural pollution. Implementation of BMPs at the farm level is to be achieved through the existing and expanded provision of education, financial assistance, technical assistance, applied research and demonstrations.

Involvement at the local level has been through the local boards of the State Soil and Water Conservation Commission. Recently, in an attempt to increase involvement at the local level in the Chesapeake Bay program, governors of the three states have appointed representatives of local governments in the Bay region to the Local Government Advisory Committee to plan for local activities.

## *Programs*

Federal agencies have made available financial and technical assistance to encourage producers to implement BMPs. SCS is responsible for providing technical assistance to farmers. ASCS administers the federal cost sharing program which provides financial assistance to producers for implementing approved BMPs. CES has served an education role, providing information to governments and individuals on the agricultural nonpoint pollution problems and available solutions. The state's BMP cost sharing program provides financial assistance, beyond that provided by ASCS, for the implementation of approved BMPs.

A recent modification of water quality management activities has been the increased attention to nutrients as a specific component of agricultural nonpoint pollution. The CBA includes a goal of reducing both nitrogen and phosphorus loads to the Bay by 40 percent. Recognizing that point source controls will not meet this goal alone, nonpoint source, and in particular agricultural nonpoint source, controls are being reexamined.

The requirement to develop and implement a comprehensive plan to control various type of pollutants (required by both the CWA and the CBA) and the accompanying search for effective approaches for reducing agricultural nonpoint pollution  suggest that water quality policy may be strengthened by alternative and innovative approaches for reducing nutrient pollution to the Chesapeake Bay and its tributaries. In particular, programs designed to encourage farmers′ conversion to alternative production systems which incorporate specific nitrogen management strategies may be especially effective. The results presented in chapter four suggest that the alternative production systems considered may reduce nitrogen residuals by 14 to 35 percent from the level of the conventional system over a ten year period. It is important, however, to consider how a particular program will be received by producers and whether it will have the desired impact on production decisions.

## Changing Adoption Incentives

The policy and adoption process can be represented by the scenario in figure 7.1, where a targeted group of producers is being asked to consider the adoption of an alternative production system or systems. The producers face a set of constraints which influence, positively or negatively, adoption decisions.

The positive constraints include incentives which exist to encourage the adoption of an alternative system. If only positive constraints are encountered, adoption is likely to occur. Negative constraints, on the other hand, include disincentives to adoption and may include financial disincentives, negative attitudes, and poor or incomplete information. In the context of negative constraints, the goal of the water quality policy is to change the incentives which discourage producers from adopting the desired production systems to reduce residual nitrogen. Both financial and attitudinal/information disincentives may require attention.

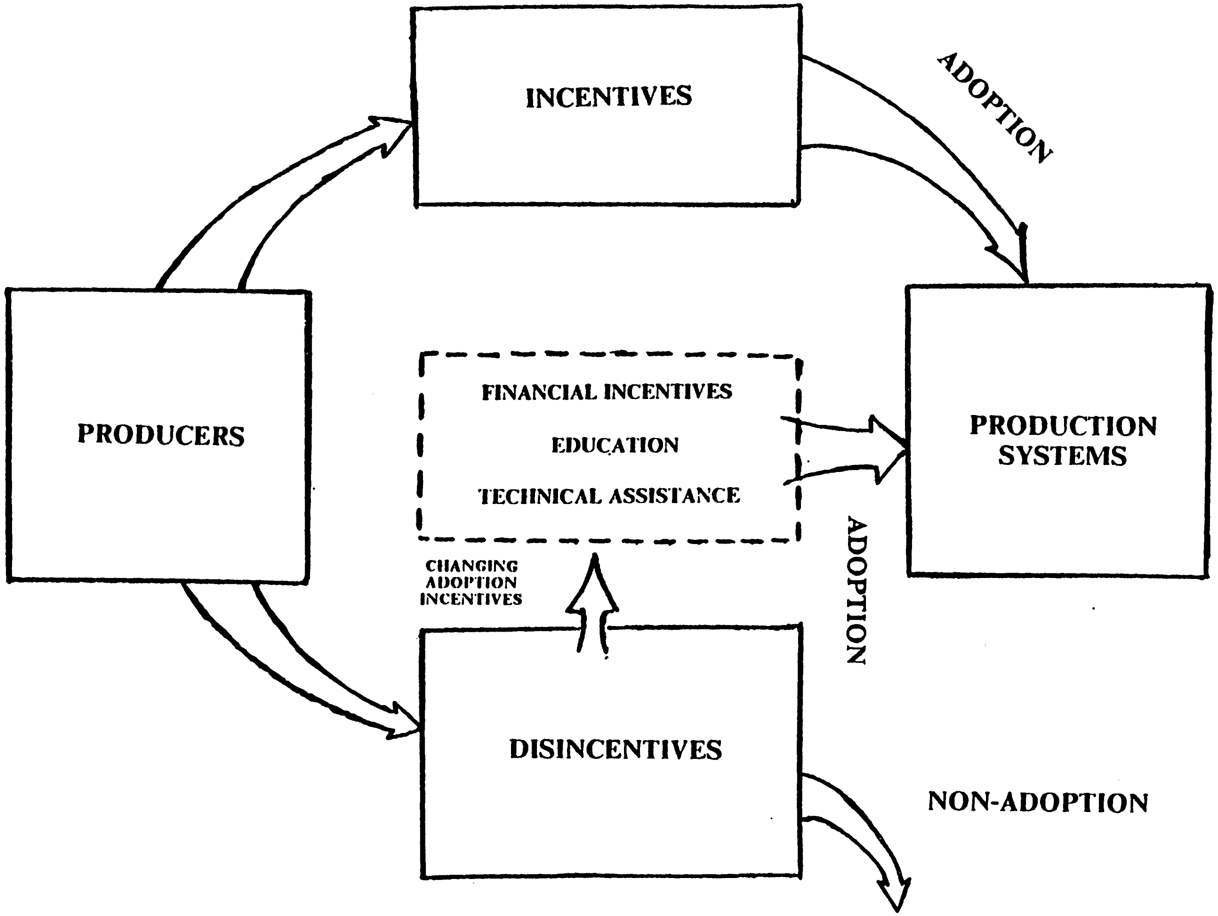

Figure 7.1. The Adoption Process From a Policy Perspective

## *Changing Economic Incentives*

The model results presented in chapter four show the relative profitability of seven alternative production systems, each of which incorporates a specific nitrogen management strategy. Financial incentives for conversion to an alternative system exist if, for a specific alternative system, net returns from the alternative exceed net returns from the conventional system over the producer's planning horizon. The profit-maximizing producer will adopt an alternative system if a positive financial incentive exists. As shown in chapter four, financial incentives exist which should encourage the conversion from the CONV system to the SPLN system, the AR system, or the PL system. However, a financial disincentive exists which is likely to prevent producers from adopting the WC, LWC or AR/WC system. Thus, one goal of a water quality policy might be to change the financial incentives associated with these systems and improve their profitability relative to the conventional system.

Financial disincentives may also exist if significant transition costs are associated with the conversion to an alternative system. At the time of transition to an alternative production system, management and information problems may result in an initial decline in net returns. For example, when organic sources of nitrogen are substituted for inorganic nitrogen fertilizer, a decline in net returns may result from the inadequate estimation of the nitrogen value of legumes, the introduction of a weed problem from manures, and the need initially to use both organic and inorganic nitrogen to maintain crop yields. Over time, costs for external nitrogen and management problems should decrease, although it is possible that costs will outweigh net returns over the whole planning period. Thus, an additional policy goal might be to offset the initial costs which might be associated with conversion to an alternative production system.

Two specific approaches which might be used to change the economic incentives for adopting alternative nitrogen management strategies include taxes or fees and subsidies (Harrington et al.). As an economic incentive, taxes and fees increase the cost of a particular activity, making some alternative activity economically more attractive. For example, a tax on nitrogen fertilizer might be expected to reduce its use and encourage interest in alternative nitrogen sources. Conversely, a subsidy is a payment made to encourage a particular behavior, and may take the form of direct cash payments, guaranteed prices, tax exemptions, insurance, and low interest loans. Subsidies might also be used to encourage producers to adopt some alternative nitrogen management strategy.

**Nitrogen Fertilizer Tax**

A tax on nitrogen fertilizer as an approach for changing the economic incentives for nitrogen management has been widely discussed (Braden; Anonymous, 1987). Table 7.1 presents the impacts of a 10 cent per pound tax on nitrogen fertilizer on the net returns for the production systems considered in chapter three. As expected, those systems which depend less heavily on inorganic nitrogen fertilizer are less affected by the tax.

In the "without tax" scenario, the PVNR from the CONV system exceeded net returns from the WC, LWC and AR/WC systems by 17, 7 and 8 percent respectively. With a 10 cent per pound tax over a ten year period, returns from the LWC and AR/WC systems exceed net returns from the CONV system by 6 and 7.5 percent, respectively. The CONV system net returns remain higher than the returns to the WC system, but the difference is reduced slightly.

With a 10 cent per pound tax, the SPLN system still dominates the CONV system. Since the increased nitrogen cost represents a smaller proportion of total input costs for the SPLN system, the nitrogen tax reduces net returns by 16 percent, as compared to a 25 percent reduction for the CONV system. The PL system remains the most profitable, since production costs are unaffected by the nitrogen fertilizer tax.

An important question, however, is whether such a tax would strongly influence producers′ nitrogen management decisions. When asked in the survey whether a 10 cent per pound tax on nitrogen fertilizer would encourage them to use an alternative production system and nitrogen management strategy, approximately half of the producers stated that such an incentive would influence their decisions. As shown in table 7.2, 52 percent of the producers not currently using a split nitrogen system said a 10 cent per pound tax on nitrogen fertilizer would encourage them to use such a system.

**Table 7.1. Present Value of Net Returns, Per Acre, From Production Systems With and Without a $.10 per Pound Tax on Inorganic Nitrogen Fertilizer**

| | PVNR Over Ten Years | |
|---|---|---|
| System | Without Tax | With Tax |
| CONV | 464.31 | 349.16 |
| (index) | (100.0) | (100.0) |
| SPLN | 540.36 | 453.39 |
| | (116.4) | (129.9) |
| WC | 394.20 | 289.96 |
| | (84.9) | (83.1) |
| LWC | 432.91 | 370.13 |
| | (93.2) | (106.0) |
| AR | 509.9 | 433.29 |
| | (109.8) | (124.0) |
| AR/WC | 423.44 | 375.36 |
| | (91.2) | (107.5) |
| PL | 648.86 | 648.86 |
| | (139.8) | (185.8) |

**Table 7.2. Responses of Producers to a Hypothetical $.10 per Pound Tax on Inorganic Nitrogen Fertilizer as an Incentive to Use An Alternative Nitrogen Management Strategy (For Those Producers Not Currently Using the Strategy)**

| | Possible Responses[1] | | | |
|---|---|---|---|---|
| | 4 | 3 | 2 | 1 |
| System Description | (percent responding) | | | |
| Split applications of nitrogen | 18.0 | 34.0 | 18.0 | 30.0 |
| Using a nitrogen-fixing legume as a green manure | 25.64 | 28.21 | 19.23 | 26.92 |
| Using livestock manure to supply nitrogen | 15.49 | 26.76 | 32.39 | 25.35 |
| Using composted poultry litter to supply nitrogen | 21.25 | 30.0 | 27.5 | 21.25 |

[1] Possible responses - 4 represents "Would strongly encourage me"; 1 represents "Would not encourage me"

Approximately 54 percent of those producers not using legume green manures to provide nitrogen said a 10 cent per pound tax on nitrogen fertilizer would encourage them to use legume green manures. Only 42 percent of those not using livestock manure would be encouraged to do so by a 10 cent per pound tax on nitrogen fertilizer. (No doubt this figure reflects the need to have livestock for a source of manure - a decision much less likely to be affected by a tax on nitrogen fertilizer.) Fifty- one percent of the producers said a 10 cent tax would encourage them to use poultry litter as a source of nitrogen.

To predict which producers would be influenced by an incentive like the nitrogen tax, a LOGIT analysis was conducted on the following models:

$$TAXSPL = f(SPRA1, SPRA2, COMP, CPXSPL, SIZE, EDUC1, EDUC2, EDUC3, EDUC4, FP, ENVIR, CHANGE, INFO, COMMUN) \quad [7.1]$$

and

$$TAXLEG = f(LGRA1, LGRA2, COMP, CPXLEG, SIZE, EDUC1, EDUC2, EDUC3, EDUC4, FP, PLAN, ENVIR, CHANGE, INFO, COMMUN) \quad [7.2]$$

where *TAXSPL* equals 1 if the producer responded that a 10 cent per pound tax on nitrogen fertilizer would encourage him to use a split nitrogen application system, 0 otherwise. *TAXLEG* equals 1 if the producer responded that a 10 cent per pound tax would encourage him to use a legume green manure, 0 otherwise. All of the independent variables are defined as discussed in chapter six.

The results in table 7.3 suggest that, at the .10 level of significance, *COMP*, *EDUC2*, *FP* and *SIZE* are the variables which predict whether a producer's adoption of the split nitrogen system would be influenced by the tax. The model correctly predicts the response of 83 percent of the observations, and the likelihood ratio test is significant at the .01 level.

Producers who grow corn are more likely to be influenced by the tax than those who do not grow corn. Since nitrogen fertilizer represents as much as 25 percent of the variable input costs for corn production, this is not a surprising result. Full-time farmers are less likely to be influenced by the tax than part time farmers. This is somewhat surprising since part-time farmers might be expected to face time and information constraints which might be more important in their decisions than the imposition of such a tax. Producers who have completed some college are more likely to be influenced by the tax than producers who have not completed high school. Finally, operators of larger farmers are less likely to be influenced by a fertilizer tax. Interestingly, perception of the costliness of the split nitrogen system did not influence how the producers responded to the fertilizer tax idea, nor did the *CPXSPL* variable which measured producers' knowledge of the split nitrogen system.

Table 7.4 shows the variables which predict whether a producer would be encouraged by a fertilizer tax to use a legume green manure. At the .10 level, CPXLEG, EDUC3, EDUC4, INFO, and ENVIR are the significant factors. Producers with more information about the legume green manure system are more likely to be influenced by the fertilizer tax. Also, producers with more education are more likely to be influenced by the tax. Producers who actively seek information on

Table 7.3. Results of LOGIT Estimation of TAXSPL Model

| Variable | Coefficient | t-ratio |
|---|---|---|
| SPRA1 | -.1487 | -.1659 |
| SPRA2 | -.0303 | -.0331 |
| COMP | 6.392 | 2.590 |
| CPXSPL | 2.024 | 1.625 |
| SIZE | -.0023 | -2.201 |
| EDUC1 | 2.157 | 1.347 |
| EDUC2 | 6.332 | 2.051 |
| EDUC3 | 25.85 | .0003 |
| EDUC4 | 33.48 | .0003 |
| FP | -3.129 | -1.800 |
| ENVIR | .1336 | .3011 |
| CHANGE | .3738 | .9657 |
| INFO | 94790 | .6473 |
| COMMUN | 2.368 | 1.610 |
| Constant | -14.976 | |

N = 47
Likelihood ratio = 37.87, 14 d.f.
t($\alpha$ = .10, two-tailed) = 1.694

**Table 7.4. Results of LOGIT Estimation of TAXLEG Model**

| Variable | Coefficient | t-ratio |
|---|---|---|
| LGRA1 | -.3132 | -.8050 |
| LGRA2 | .2070 | .4333 |
| COMP | .9024 | .9102 |
| CPXLEG | .4720 | 1.800 |
| SIZE | .00003 | .0757 |
| EDUC1 | 1.205 | 1.355 |
| EDUC2 | 1.082 | 1.005 |
| EDUC3 | 2.680 | 1.782 |
| EDUC4 | 3.610 | 2.045 |
| FP | .3110 | .3932 |
| PLAN | .5209 | .6847 |
| ENVIR | -.3947 | -1.863 |
| CHANGE | -.0166 | -.0974 |
| INFO | 1.570 | 2.064 |
| COMMUN | -.0848 | -.1664 |
| Constant | -3.085 | |

N = 67
Likelihood ratio = 23.80, 15 d.f.
$t(\alpha = .10$, two-tailed) = 1.677

alternative nitrogen sources are more likely to be influenced by the tax, as are producers who are concerned over the environmental impacts of production practices. The model correctly predicted the response of 75 percent of the observations, and the likelihood ratio test is significant at the .10 level.

Results of this analysis and the survey responses suggest that a tax on nitrogen fertilizer might be expected to impact the decisions of a substantial number of producers. Questions have arisen about the disposition of the revenues collected by such a tax (Harrington et al.). However, if the fertilizer tax is imposed at a level to influence producers' decisions, disposition concerns might be eased by earmarking tax receipts for water quality programs to provide funds for cost sharing and education to aid farmers in making the transition to alternative production systems.

**Per Acre Subsidy for Conversion**

Another approach which might be used to change the economic incentives for conversion to an alternative production system is a direct cash payment for conversion. Providing a per acre subsidy, for a specified period of time, to producers who use an alternative nitrogen management strategy on a set acreage could serve to increase the net returns from a particular alternative relative to the conventional system or to offset any initial costs of conversion to the alternative system.

An example of this type of incentive exists in the current DSWC BMP Cost Share Program. Under its Cost Share Program, the DSWC provides a $25.00 per acre payment for acreage "utilizing an adequate legume mulch residue as a natural source of nitrogen to reduce applied soil amendment nitrogen (DSWC)." The BMP specification requires that the legume stand be used as a mulch cover for no-till corn and that applied fertilizer nitrogen be reduced by 40 pounds per acre from the producer's standard rate of application.

Table 7.5 shows the impact of an annual payment of $25.00 per acre on the present value of net returns for each production system described in chapter three. The PVNR of the CONV system is presented as a benchmark, and the PVNR for each system resulting from a one time payment of $25.00 per acre up to an annual payment each year for five years is presented. If a payment of $25.00 per acre was made for two years, the net returns from the LWC and the AR/WC systems would exceed the CONV system net returns; a per year payment for three years would increase the net returns from the WC system above the net returns from the CONV system.

**Table 7.5. Impact on Present Value of Net Returns From Alternative Production Systems of $25.00 Per Acre Direct Cash Subsidy for Conversion**

| | PVNR Over Ten Years | | | | | | |
|---|---|---|---|---|---|---|---|
| Years of Subsidy | Production System<br>CONV | SPLN | WC | LWC | AR | AR/WC | PL |
| 0 | 464.31 | 540.36 | 394.20 | 432.91 | 509.90 | 423.46 | 648.86 |
| 1 | - | 565.36 | 419.20 | 457.90 | 534.90 | 448.44 | 673.86 |
| 2 | - | 589.17 | 443.01 | 481.71 | 558.71 | 472.25 | 697.67 |
| 3 | - | 611.85 | 465.69 | 504.39 | 581.39 | 494.93 | 720.35 |
| 4 | - | 633.46 | 487.29 | 525.98 | 602.99 | 516.53 | 741.94 |
| 5 | - | 684.03 | 507.85 | 546.55 | 623.56 | 537.10 | 762.51 |

The table shows the impact on net returns of making the $25.00 per acre payment for up to five years. This incentive can be used to substantially increase the profitability of the alternative systems and offset any initial costs of conversion. However, as with the fertilizer tax, the direct cash subsidy approach will not be effective as a water quality policy if it does not influence producers′ decisions.

Table 7.6 presents producers′ responses to a hypothetical $25.00 per acre payment as an incentive for using four alternative systems. When asked whether a $25.00 per acre payment would encourage them to use a split nitrogen system, 75 percent of the producers not currently using the system responded positively. Eighty-seven percent of the producers not currently using a legume green manure responded that such a payment would encourage them to use a legume green manure. Seventy-four percent of the producers not using livestock manure said a $25.00 per acre payment would encourage them to use manure as a source of nitrogen. (Again, these responses depend on the decision to have livestock on the farm.) Finally, 85 percent of the producers said a \$25.00 per acre payment would encourage them to use poultry litter as a source of nitrogen.

**Table 7.6. Responses of Producers to a Hypothetical \$25.00 Per Acre Payment as an Incentive to Use An Alternative Nitrogen Management Strategy (For Those Producers Not Currently Using the Strategy)**

| | Possible Responses[1] | | | |
|---|---|---|---|---|
| | 4 | 3 | 2 | 1 |
| System Description | (percent responding) | | | |
| Split applications of nitrogen | 50.94 | 24.53 | 9.43 | 15.09 |
| Using a nitrogen-fixing legume as a green manure | 58.54 | 28.05 | 7.32 | 6.10 |
| Using livestock manure to supply nitrogen | 45.83 | 27.78 | 15.28 | 11.11 |
| Using composted poultry litter to supply nitrogen | 47.62 | 36.90 | 9.52 | 5.95 |

[1] Possible responses - 4 represents "Would strongly encourage me"; 1 represents "Would not encourage me"

Again, LOGIT analysis was used to predict which producers would be influenced by a \$25.00 per acre payment. The models estimated were:

$$PAYSPL = f(SPRA1, SPRA2, COMP, CPXSPL, SIZE, EDUC1, EDUC2, EDUC3, EDUC4, FP, ENVIR, CHANGE, INFO, COMMUN) \qquad [7.3]$$

and

$$PAYLEG = f(LGRA1, LGRA2, COMP, CPXLEG, SIZE, EDUC1, EDUC2, EDUC3, EDUC4, FP, PLAN, ENVIR, CHANGE, INFO, COMMUN) \qquad [7.4]$$

where *PAYSPL* equals 1 if the producer responded that a $25.00 per acre payment would encourage him to use a split nitrogen system, 0 otherwise. *PAYLEG* equals 1 if the producer responded that a $25.00 per acre payment would encourage him to use a legume green manure, 0 otherwise. The independent variables are defined as discussed previously.

The results in table 7.7 show that producers who grow corn are more likely to be encouraged by the payment to use a split nitrogen system than those who do not grow corn. Also, those producers who consult a larger number of information sources are more likely to be influenced by the incentive. The model correctly predicted the response of 89 percent of the observations, and the likelihood ratio test was significant at the .15 level.

Table 7.8 shows the results of the *PAYLEG* estimation. At the .10 level of significance, *LGRA2*, is the factor which influences producers' response to the payment incentive. Producers who agree that using the legume reduces the amount of nitrogen lost from the field during the storm are more likely to be influenced by the payment. The model correctly predicted the responses of 88 percent of the observations, and the likelihood ratio test was significant at the .20 level.

Despite its potential for changing producers' behavior, the direct cash subsidy will not successfully improve water quality if it is not carefully applied. For example, there are three specific limitations associated with the current DSWC BMP which makes use of the direct cash subsidy which may limit its effectiveness for reducing nitrogen pollution. First, the requirement that no-till be used is intended to serve an erosion control purpose. However, in some areas, minimum tillage practices can be used without substantial erosion hazard. Incorporating the legume mulch in the soil will increase the decay of the mulch and the subsequent availability of nitrogen for the following crop. Also, no-till has been suspected of increasing nitrate leaching to ground water in some cases (Knisel et al.). Thus, a strict no-till requirement may offset some expected benefits of the BMP.

A second limitation is the strict specification that corn be planted; a legume green manure will provide nitrogen for other crops, such as grain sorghum. Finally, the requirement that nitrogen fertilizer be reduced by 40 pounds per acre may be too restrictive. If the legume stand is poor, 40 pounds may be too large a reduction. If a good stand is achieved, 40 pounds per acre is quite low relative to the nitrogen which the legume can provide. An alternative might be to have the legume

## Table 7.7. Results of LOGIT Estimation of PAYSPL Model

| Variable | Coefficient | t-ratio |
|---|---|---|
| SPRA1 | .2296 | .3983 |
| SPRA2 | .2802 | .5499 |
| COMP | 2.594 | 1.864 |
| CPXSPL | .6087 | .9399 |
| SIZE | .-0001 | .-0708 |
| EDUC1 | .7482 | .5742 |
| EDUC2 | .6161 | .4180 |
| EDUC3 | -1.012 | -.5942 |
| EDUC4 | 26.51 | .0001 |
| FP | -1.684 | -1.293 |
| ENVIR | .0719 | .2339 |
| CHANGE | -.1328 | -.5273 |
| INFO | 1.729 | 1.573 |
| COMMUN | 2.054 | 2.110 |
| Constant | -4.296 | |

N = 47
Likelihood ratio = 20.09, 14 d.f.
t($\alpha$ = .10, two-tailed) = 1.694

Table 7.8. Results of LOGIT Estimation of PAYLEG Model

| Variable | Coefficient | t-ratio |
|---|---|---|
| LGRA1 | -.9956 | -1.260 |
| LGRA2 | 1.389 | 1.838 |
| COMP | -.8816 | -.5374 |
| CPXLEG | .5781 | 1.258 |
| SIZE | -.0002 | -.2940 |
| EDUC1 | .6742 | .4482 |
| EDUC2 | -2.814 | -1.608 |
| EDUC3 | -.9534 | -.5334 |
| EDUC4 | 27.83 | .0001 |
| FP | -.8916 | -.6929 |
| PLAN | -.2139 | -.1746 |
| ENVIR | -.1007 | -.3201 |
| CHANGE | -.3001 | -.9537 |
| INFO | 2.356 | 1.615 |
| COMMUN | .2168 | .2395 |
| Constant | .5027 | |

N = 67
Likelihood ratio = 19.57, 15 d.f.
t($\alpha$ = .10, two-tailed) = 1.677

mulch tested for nitrogen content and the results of the tissue test used as a basis for the nitrogen reduction specification.

**Input Subsidy or Cost Sharing**

Subsidizing the production costs of alternative production systems is another approach for changing the financial incentives for conversion to an alternative production system. Such an approach could be used to offset conversion costs or improve the relative profitability of alternative systems. Input subsidies can be implemented in several ways.

As one example, low interest loans could be made available to producers who use an alternative production system. Reducing the cost of borrowed operating capital would be one approach to reducing production costs for alternative systems. Table 7.9 shows the impacts on net returns from the six alternative systems relative to the CONV system of providing a two percentage point reduction in the interest rate charged for short term production loans. The impact of subsidizing interest rates from one to 10 years is shown. (The net returns from the systems at the original 10.5 percent is shown as a benchmark.)

At an interest rate of 8.5 percent, the PVNR from the SPLN, AR and PL systems could be increased and possibly overcome any costs of conversion. However, providing an interest rate of 8.5 percent for the full 10 years under consideration does not increase the net returns to the WC, LWC, or AR/WC systems above net returns to the CONV system.

Table 7.10 shows the impact on net returns of providing operating capital at a cost of 6.5 percent. The LWC system net returns would exceed the net returns to the CONV system if a 6.5 percent interest rate was provided for six years or more. Provision of a 6.5 percent interest rate for 8 years or more would increase the net returns from the AR/WC system relative to the CONV system.

The impacts on net returns of an interest rate of 4.5 percent is shown in table 7.11. A loan rate of 4.5 percent for 4 years or more would improve the net returns of the LWC system relative to the CONV system, and 4.5 percent interest for 5 years or more would improve the net returns to the AR/WC system. Eight or more years of 4.5 percent interest would improve the net returns from the WC system relative to the CONV system.

**Table 7.9. Impact on Present Value of Net Returns From Alternative Production Systems of Subsidizing Interest Rates on Borrowed Operating Capital, from 10.5% to 8.5%**

| | PVNR Over Ten Years | | | | | | |
|---|---|---|---|---|---|---|---|
| Years of Subsidy | Production System | | | | | | |
| | CONV | SPLN | WC | LWC | AR | AR/WC | PL |
| 0 | 464.31 | 540.36 | 394.20 | 432.91 | 509.90 | 423.46 | 648.86 |
| 1 | - | 543.62 | 397.85 | 436.57 | 513.10 | 426.85 | 651.94 |
| 2 | - | 546.73 | 401.28 | 439.80 | 516.13 | 429.94 | 654.84 |
| 3 | - | 549.69 | 404.54 | 442.85 | 519.02 | 432.88 | 657.58 |
| 4 | - | 552.52 | 407.61 | 445.71 | 521.76 | 435.64 | 660.18 |
| 5 | - | 555.20 | 410.57 | 448.42 | 524.38 | 438.27 | 662.65 |
| 6 | - | 557.56 | 413.37 | 451.00 | 526.88 | 440.77 | 665.01 |
| 7 | - | 560.20 | 416.04 | 453.46 | 529.25 | 442.15 | 667.25 |
| 8 | - | 562.52 | 418.58 | 455.80 | 531.51 | 445.42 | 669.39 |
| 9 | - | 564.73 | 421.01 | 458.03 | 533.66 | 447.59 | 671.42 |
| 10 | - | 566.83 | 423.31 | 460.15 | 535.72 | 449.64 | 673.36 |

Finally, table 7.12 shows the impact of providing operating capital at an interest rate of 2.5 percent. If the interest rate were subsidized at 2.5 percent for 3 years, net returns from the LWC system would exceed net returns from the CONV system; if the 2.5 percent interest rate was applied to the AR/WC system for 4 years, net returns would exceed those from the CONV system. Returns from the WC system would exceed CONV system net returns if the 2.5 percent interest rate was provided for 6 years.

An alternative input subsidy approach might involve cost sharing the cost of specific production inputs involved in a particular system. For example, subsidizing the costs associated with

**Table 7.10. Impact on Present Value of Net Returns From Alternative Production Systems of Subsidizing Interest Rates on Borrowed Operating Capital, from 10.5% to 6.5%**

| | PVNR Over Ten Years | | | | | | |
|---|---|---|---|---|---|---|---|
| Years of Subsidy | Production System | | | | | | |
| | CONV | SPLN | WC | LWC | AR | AR/WC | PL |
| 0 | 464.31 | 540.36 | 394.20 | 432.91 | 509.90 | 423.46 | 648.86 |
| 1 | - | 546.88 | 401.51 | 440.23 | 516.30 | 430.25 | 655.03 |
| 2 | - | 553.10 | 408.37 | 446.69 | 522.36 | 436.45 | 660.83 |
| 3 | - | 559.03 | 414.88 | 452.78 | 528.14 | 442.31 | 666.30 |
| 4 | - | 564.67 | 421.03 | 458.51 | 533.63 | 447.84 | 671.51 |
| 5 | - | 570.04 | 426.95 | 463.92 | 538.87 | 453.10 | 676.45 |
| 6 | - | 575.16 | 432.55 | 469.08 | 543.85 | 458.10 | 681.16 |
| 7 | - | 580.03 | 437.89 | 474.00 | 548.60 | 462.87 | 685.65 |
| 8 | - | 584.67 | 442.97 | 478.68 | 553.12 | 467.41 | 689.92 |
| 9 | - | 589.09 | 447.82 | 483.14 | 557.43 | 471.73 | 693.99 |
| 10 | - | 593.30 | 452.43 | 487.38 | 561.53 | 475.85 | 697.87 |

using a legume green manure could be used to reduce the costs of such a system. Table 7.13 presents the impacts on net returns for the LWC system and the AR/WC system for three scenarios. First, the impact of subsidizing the cost of the cover crop seed is shown. Second, the impact of subsidizing the machinery costs of seeding and turning under the cover crop is shown. Finally, the impact of subsidizing the total costs (excluding labor) of seeding and incorporating the cover crop is shown.

For the LWC system, covering the cost of the legume seed for five years would make the net returns from the system approximately equal to the CONV system. If the seed costs were covered

**Table 7.11. Impact on Present Value of Net Returns From Alternative Production Systems of Subsidizing Interest Rates on Borrowed Operating Capital, from 10.5% to 4.5%**

| | PVNR Over Ten Years | | | | | | |
|---|---|---|---|---|---|---|---|
| | Production System | | | | | | |
| Years of Subsidy | CONV | SPLN | WC | LWC | AR | AR/WC | PL |
| 0 | 464.31 | 540.36 | 394.20 | 432.91 | 509.90 | 423.46 | 648.86 |
| 1 | - | 550.15 | 405.17 | 443.89 | 519.50 | 433.66 | 658.12 |
| 2 | - | 559.48 | 415.46 | 453.58 | 528.60 | 442.95 | 666.81 |
| 3 | - | 568.36 | 425.22 | 462.71 | 537.25 | 451.74 | 675.03 |
| 4 | - | 576.82 | 434.45 | 471.30 | 545.50 | 460.04 | 682.83 |
| 5 | - | 584.88 | 443.33 | 479.43 | 553.35 | 467.92 | 690.25 |
| 6 | - | 592.56 | 451.73 | 487.17 | 560.83 | 475.43 | 697.31 |
| 7 | - | 599.87 | 459.74 | 494.54 | 567.95 | 482.58 | 704.04 |
| 8 | - | 606.83 | 467.36 | 501.56 | 574.74 | 489.39 | 710.45 |
| 9 | - | 613.46 | 474.63 | 508.25 | 581.20 | 495.87 | 716.56 |
| 10 | - | 619.77 | 481.54 | 514.62 | 487.35 | 502.05 | 722.37 |

for 6 years, then net returns would exceed the CONV system net returns. Covering just machinery costs, net returns from the LWC system would be improved if the subsidy was given for eight years. Covering total costs for three years would make the LWC system competitive with the CONV system.

For the AR/WC system, covering seed costs (legume and rye) for 6 years would make the system competitive with the CONV system. If total costs were subsidized for 4 years, the net returns would exceed net returns from the CONV system.

**Table 7.12. Impact on Present Value of Net Returns From Alternative Production Systems of Subsidizing Interest Rates on Borrowed Operating Capital, from 10.5% to 2.5%**

| | PVNR Over Ten Years | | | | | | |
|---|---|---|---|---|---|---|---|
| Years | Production System | | | | | | |
| of Subsidy | CONV | SPLN | WC | LWC | AR | AR/WC | PL |
| 0 | 464.3 | 540.36 | 394.20 | 432.91 | 509.90 | 423.46 | 648.86 |
| 1 | - | 553.41 | 408.82 | 447.55 | 522.71 | 437.06 | 661.21 |
| 2 | - | 565.85 | 422.54 | 460.47 | 534.83 | 449.45 | 672.80 |
| 3 | - | 577.69 | 435.56 | 472.65 | 546.37 | 461.18 | 683.75 |
| 4 | - | 588.98 | 447.87 | 484.10 | 557.37 | 472.24 | 694.16 |
| 5 | - | 599.72 | 459.70 | 494.93 | 567.84 | 482.75 | 704.04 |
| 6 | - | 609.95 | 470.91 | 505.25 | 577.81 | 492.76 | 713.47 |
| 7 | - | 619.70 | 481.59 | 515.08 | 587.31 | 502.29 | 722.44 |
| 8 | - | 628.98 | 491.75 | 524.44 | 596.35 | 511.37 | 730.99 |
| 9 | - | 637.82 | 501.44 | 533.36 | 604.97 | 520.02 | 739.13 |
| 10 | - | 646.24 | 521.66 | 541.85 | 613.17 | 528.25 | 746.88 |

Despite producers′ interest in organic sources of nitrogen, their incorporation into production systems is hampered when such materials are not widely available. Producers are well aware of the benefits of using livestock manure as a soil amendment. However, there is only limited livestock production in the study area, and wastes produced are concentrated at livestock operations, which limits the access of grain producers to such materials. While the grain producers cannot be expected to assume the production of livestock as a source of organic nitrogen, a regional perspective of the farming system would suggest that livestock wastes might be available from off-farm sources, combining animal waste management for livestock producers with crop fertilization practices for

**Table 7.13. Impact on Present Value of Net Returns From LWC and AR/WC Production Systems When Seed, Machinery and Total (excluding labor) Costs of Cover Crops are Subsidized**

| | PVNR Over Ten Years | | | | | |
|---|---|---|---|---|---|---|
| | LWC | | | AR/WC | | |
| | Input Costs Subsidized | | | | | |
| Years of Subsidy | Seed | Mach. | Total | Seed | Mach. | Total |
| 0 | 432.91 | 432.91 | 432.91 | 423.44 | 423.44 | 423.44 |
| 1 | 439.96 | 437.87 | 444.91 | 432.14 | 428.19 | 435.90 |
| 2 | 446.68 | 442.58 | 456.34 | 438.48 | 432.72 | 447.76 |
| 3 | 453.07 | 447.07 | 467.23 | 445.47 | 437.03 | 459.05 |
| 4 | 459.16 | 451.35 | 477.59 | 452.12 | 441.14 | 469.81 |
| 5 | 464.96 | 455.42 | 487.47 | 458.45 | 445.04 | 480.05 |
| 6 | 470.49 | 459.30 | 496.87 | 464.49 | 448.77 | 489.81 |
| 7 | 475.75 | 462.99 | 505.82 | 470.24 | 452.31 | 499.10 |
| 8 | 480.76 | 466.51 | 514.35 | 475.71 | 455.69 | 507.95 |
| 9 | 485.53 | 469.86 | 522.46 | 480.92 | 458.90 | 516.38 |
| 10 | 490.07 | 473.05 | 530.21 | 485.89 | 461.97 | 524.41 |

grain farmers in a regional or watershed-level farming system. Providing economic incentives to promote such a system is another example of an input subsidy, by increasing the availability of inputs.

As an example, an experimental program is being conducted by the Cooperative Extension Service which involves transporting poultry litter from the poultry-producing region of Virginia to the grain producing area of eastern Virginia (Weaver et al.). The program has facilitated the use of grain trucks, which haul grain from eastern Virginia to the poultry region and would otherwise return empty, to transport composted poultry litter to eastern Virginia and has encouraged a number of grain producers to use the litter on an experimental basis. The "backhauling project", the costs of which have been subsidized by the state government, represents an important effort to educate producers about the use of poultry litter and to demonstrate the feasibility of transporting and distributing the litter.

Such an approach to waste management has several benefits, including: 1) the opportunity for development of a new value-added agriculturally based industry focused upon the collection, processing and distribution of animal waste; 2) the opportunity to contribute to the improved profitability of animal agriculture by creating an industry which puts a positive price on the waste product; 3) the opportunity to preserve the quality of both the surface water and ground water in the area where the waste is created by distribution of animal waste to those areas where it will have added economic value as an input into crop and animal production; and 4) the opportunity to reduce nutrient contamination of waters outside the area by export of the waste as a substitute for the more readily leachable commercial fertilizer products now in use. In addition to demonstration projects, such as the poultry litter backhauling project, financial incentives to promote a waste collection and distribution "industry" could include venture capital funds and use of specialized investment tax credits.

As with the fertilizer tax and direct payments, it is not clear that the input subsidy approach would encourage a sweeping conversion to alternative production systems and nitrogen management strategies. The diffusionist perspective asserts that, despite the profitability of an alternative production system, with or without financial incentives, producers who face other constraints may not choose to adopt the alternative system. Economic incentives will not influence the decisions of producers who are not aware of the alternatives, who are misinformed or lack adequate information about alternatives, or who hold specific beliefs which preclude adoption. As shown in table 7.4, for example, producers with more knowledge about the legume green manure system are more likely to be influenced to use a legume green manure by a tax on nitrogen fertilizer.

## *Attitudes and Information as Adoption Incentives*

In order to elicit producers' knowledge about and attitudes toward alternative strategies for supplying nitrogen to crops, the farmer survey included a series of statements about alternatives. The producers were asked to indicate how strongly they agreed or disagreed with each statement, using a scale of 4 (strongly agree) to 1 (strongly disagree). The results of the survey provide some insights into producers' attitudes toward alternative systems and the base of information on which they are making decisions. For example, producers' perceptions of the costs associated with a specific system will impact the success of programs designed to change the economic incentives for adoption.

In the survey, producers were asked whether they believed each of three alternative production systems to be too costly and time consuming. Forty-nine percent of those responding felt that splitting nitrogen into two separate applications is too costly and time consuming. Almost 40 percent of the producers responding felt legume cover crops are too costly and time consuming. Using livestock manure as a source of nitrogen was believed to be too costly and time consuming by 52 percent of the producers responding. Thus, a significant proportion of the producers perceived financial constraints to the adoption of these systems. However, the effectiveness of financial incentives will be limited if, despite the relative profitability of a particular system, the producers do not have the time required to implement the system. Of the farmers surveyed, 57 percent stated they were unable to devote more time to managing the farm operation.

Second, producers' knowledge or lack of knowledge of alternative systems may present constraints to adoption. Despite the economic incentives for adoption, information constraints may prevent adoption. Conversely, producers who demonstrate adequate information and knowledge of the systems but are reluctant to use the systems confirm the potential role of financial incentives. As an example, respondents were fairly knowledgeable about split nitrogen applications. Sixty percent agreed that splitting nitrogen applications reduces the amount of nitrogen fertilizer required. Seventy-seven percent agreed that splitting nitrogen applications reduces the amount of nitrogen lost from the field during a rain storm. However, only 43 percent of the survey respondents reported using split nitrogen applications. This suggests that constraints to adoption, perhaps financial disincentives, exist for some producers despite knowledge of the benefits of the system.

Producers were less certain of the benefits of using legume green manures as a source of nitrogen. Fifty percent of those responding felt the legume could provide most of the nitrogen needed by the corn and that some nitrogen from the legume would be left for the subsequent crop. Thus, uncertainties as to the nitrogen provided by a legume green manure may be a constraint to using such a system. However, most producers (93 percent) agreed that legume green manures would improve a soil's physical properties, and 86 percent agreed that nitrogen from legumes is less likely to be lost from the field during a rain storm. Nevertheless, only 21 percent of the producers reported using this system.

When asked about using livestock manure as a source of nitrogen, 92 percent agreed manure would improve a soil's physical properties. Forty-five percent of those responding agreed manure could supply most of the nitrogen for a corn crop, while 53 percent agreed that nitrogen from the manure would be left for the next crop. Finally, 80 percent of the respondents agreed that nitrogen from manure is less likely to be lost from the field during a rain storm.

While 38 percent of the producers had livestock on their farms in 1988, only 30 percent of those producers with livestock reported using livestock manure as a source of nitrogen. However, only two producers reported a swine operations of substantial size ( > 1000 head); one producer reported a dairy operation; and nine producers reported having more than 30 head of beef cattle. Only large confined or feeding operations which concentrate a large number of animals in a central location for feeding will generate sufficient manure to be collected, stored, and used as a source of nitrogen. Respondents were not asked if their livestock were confined. However, generally swine operations exceeding 500 head are partially to fully confined (Mundy et al.). Cattle, dairy or beef, operations exceeding 30 head are likely to generate substantial quantities of manure in concentration if a central feeding location is used.

Producers were less knowledgeable about poultry litter, as evidenced, in part, by the smaller number of producers who responded to the questions about poultry litter. However, of those who did respond, 73 percent agreed that composted poultry litter can supply most of the nitrogen needed by a corn crop. Also, 66 percent agreed that some of the nitrogen would be left for the next crop, and 79 percent agreed that nitrogen in composted poultry litter is less likely to be lost from the field during a rain storm. Eighty-three percent of the respondents agreed that poultry litter will improve a soil's physical properties. Thus, many producers are aware of the benefits provided by poultry litter as a source of nitrogen. However, 41 percent of the respondents felt that composted poultry litter has an odor which they or their neighbors would find offensive, an attitude which may present a constraint to adoption.

### Implications for Education and Technical Assistance Programs

The survey results present some specific implications for education and technical assistance programs for encouraging the adoption of alternative nitrogen management strategies. Specifically, producers revealed that additional information on alternative production systems and nitrogen management strategies would encourage them to use the alternatives. In fact, the availability of additional information was rated at least as high as financial incentives, and in some cases higher, as an incentive for conversion.

Of the producers not currently using a split nitrogen system, 66 percent stated that "reliable information on the stage of growth when plants need the most nitrogen" would encourage them to use split nitrogen applications. Similarly, 67 percent would be encouraged to use a split nitrogen system by "evidence that total nitrogen applied can be reduced with split applications."

Of the producers not currently using legume green manures for nitrogen, 84 percent responded that "evidence that long term soil fertility can be enhanced by legumes" would encourage them to do so. Similarly, 78 percent of the producers not currently using livestock manure would be encouraged to do so by "evidence that long term soil fertility can be enhanced by manures." Eighty-three percent of the producers stated that they would be encouraged to use poultry litter to supply nitrogen to crops if provided with "evidence that long term soil fertility can be enhanced by poultry litter."

A water quality policy which promotes the compilation and dissemination of technical information on the production impacts of alternative nitrogen management systems is likely to be as important as financial incentives for encouraging producers to adopt alternative systems. The avenue by which information is disseminated to producers is also an important consideration. Some information sources are used more often than others and may be viewed as more reliable by producers. In the survey, producers were asked about the reliability of several sources of information on alternative approaches for supplying nitrogen to crops. In general, the extension specialists at Virginia Tech in Blacksburg were rated the most reliable, with local extension agents a close second. Other farmers were also rated as fairly reliable, while farm magazines and agricultural supply companies were rated somewhat less reliable.

Producers were also asked which sources of information were consulted when making nitrogen application decisions. Sixty percent of the producers stated that nitrogen application decisions were based on experience. Extension recommendations were consulted by 19.6 percent of the producers, while fertilizer dealer recommendations were considered by 18.6 percent of the producers. Virginia Tech soil tests and commercial soil tests were used as a guide by 32 and 42.3 percent of the producers, respectively. Three percent of the producers used other sources of information, including tissue tests.

Seventy-three percent of the producers not currently using legume green manures stated they would be encouraged to do so by the "availability of free tissue analysis service to determine nitrogen content of legumes." Of the producers not using livestock manure for nitrogen, 73 percent said that the "availability of free manure testing service to determine nitrogen content of manures" would encourage them to do so. In addition, 81 percent of the respondents stated that "dealer assurance of the nitrogen content of composted poultry litter" would encourage them to purchase poultry litter for use as a source of nitrogen.

Increased availability and accuracy of manure and tissue testing services is one approach for reducing the management costs of alternative systems. These types of services could be expected to provide a more sound basis for management decisions, decrease uncertainties regarding nitrogen content of organic residues, and decrease the likelihood of yield loss or excess expenditures on purchased inputs during the transition period. The promotion of technology to reduce management costs of alternative systems is another important policy tool. As discussed previously, many producers view the alternatives as too costly and time consuming. A reduction of the costs associated with learning and implementing the systems could be expected to positively impact adoption. In addition to tissue and manure testing, information technology, such as farm level computerization and advanced telecommunications, could provide rapid access to new information about alternative systems and reduce the learning costs associated with changing management techniques.

Finally, the perspective from which information is presented to producers is an important policy consideration. Increasing yields has been, and continues to be, the goal of most crop production information generated by agricultural research and disseminated through the extension network. Increasingly, however, producers and researchers are targeting decreased production costs as the avenue for improving agricultural profitability. This discrepancy in approaches is exemplified by research at Virginia Tech which seeks, as its objective, to obtain higher crop yields from the same amount of nitrogen fertilizer (Alley et al.). From the alternative perspective, maintaining crop yields at current levels using less nitrogen fertilizer, and, through the use of organic sources of nitrogen, continually reducing the dependence on commercial nitrogen fertilizer, incorporates the goals of sustained profitability and environmental quality.

## *Changing Adoption Incentives - A Research Perspective*

Until very recently, the land grant system has fostered agricultural research which has focused primarily on traditional, or more precisely, conventional production techniques. The research agenda has been *responsive* to current needs and activities while failing to *anticipate* future needs and consequences of agricultural production (Buttel; MacIntyre). This has been due to several factors. First, funding sources for research are often interested in studies targeted to specific problems, products, or production techniques currently in existence. By concentrating on solving current problems or expanding the use of current products, future needs are not considered. Second, physical scientists are often hesitant to introduce new ideas or technologies which have not been validated by several years of testing and experimentation. This, in turn, perpetuates the responsive/anticipatory dichotomy in agricultural research. As a final note, however, the professional rewards for research in the university system are more often realized for short term research with readily publishable results. Thus, research efforts are focused on the publishing outlet rather than the extension mission.

Ironically, the use of legume green manures and animal wastes as sources of nitrogen is not a new idea, but rather epitomizes traditional agricultural production. Research, however, has neglected these practices for the more modern, chemical-intensive production techniques. For this study, some of the most useful information for generating model coefficients for the legume systems was found in literature published as early as 1926 and 1938 (Lohnis; Pieters and McKee). The use of livestock manures as a source of nitrogen has only recently been re-examined (Gilbertson et al.; Givens), and this renewed interest has resulted because of the need to find an outlet for a waste product.

Clearly, there is a role for increased research to assure that adequate and complete information on alternative production systems is available to producers. Research should focus on the management, information and input needs associated with the alternative systems. Also, illumination and quantification of inherent uncertainties associated with the alternative systems is needed. To demonstrate this need, critical parameters of the nitrogen balance sub-model in this study were modified to examine the impact of changes in nitrogen availability, mineralization rates, and nitrogen content of poultry litter on profitability and nitrogen residuals.

First, changes in the plant availability of applied commercial fertilizers were examined. In the initial analysis, it was assumed that 60 percent of applied nitrogen fertilizer was used by crops in the CONV, WC, LWC, AR, and AR/WC systems and 80 percent was used by crops in the SPLITN system - reflecting the conditions of a typical rainfall year. However, in a wet year, significantly less nitrogen would be available to plants as more became subject to leaching and runoff. Similarly, in a dry year, more of the nitrogen would remain in place and be available to crops. Tables 7.14 and 7.15 show the impact on net returns and residual nitrogen from the alternative systems of varying the nitrogen availability coefficient to reflect different climatic conditions. The coefficients were varied for the full ten year period to provide a conservative picture of the impacts.

**Table 7.14. Impact of Availability of Nitrogen Fertilizer on Present Value of Net Returns and Residual Nitrogen, per acre, Over Ten Year Period**

| | PVNR<br>$/acre | | | Residual Nitrogen<br>lbs/acre | | |
|---|---|---|---|---|---|---|
| | (percent of applied nitrogen available to crop) | | | | | |
| System | 60 % | 50 % | 40 % | 60 % | 50 % | 40 % |
| CONV | 464.31 | 404.24 | 315.40 | 647.0 | 856.9 | 1162.0 |
| WC | 394.20 | 339.83 | 259.43 | 556.2 | 734.8 | 998.8 |
| LWC | 432.91 | 400.17 | 351.76 | 425.8 | 523.9 | 669.1 |
| AR | 509.90 | 469.93 | 410.82 | 525.9 | 665.8 | 872.5 |
| AR/WC | 423.44 | 398.37 | 361.29 | 439.8 | 522.8 | 640.1 |
| | 80 % | 70 % | | 80 % | 70 % | |
| SPLN | 540.36 | 507.63 | | 428.9 | 550.0 | |

**Table 7.15. Impact of Increased Availability of Nitrogen Fertilizer on Present Value of Net Returns and Residual Nitrogen, per acre, Over Ten Year Period**

| | PVNR<br>$/acre | | | Residual Nitrogen<br>lbs/acre | | |
|---|---|---|---|---|---|---|
| | (percent of applied nitrogen available to crop) | | | | | |
| System | 60 % | 70 % | 80 % | 60 % | 70 % | 80 % |
| CONV | 464.31 | 507.63 | 509.11 | 647.0 | 494.7 | 383.9 |
| WC | 394.20 | 433.41 | 463.03 | 556.2 | 427.5 | 377.6 |
| LWC | 432.91 | 456.53 | 474.37 | 425.8 | 354.6 | 352.7 |
| AR | 509.90 | 538.72 | 560.50 | 525.9 | 425.0 | 351.5 |
| AR/WC | 423.44 | 455.19 | 441.53 | 439.8 | 381.6 | 359.0 |
| | 80 % | 70 % | | 80 % | 70 % | |
| SPLN | 540.36 | 565.96 | | 428.9 | 287.0 | |

In table 7.14, the impacts of lower availability of nitrogen fertilizer (as might be expected in wet years) are shown. In terms of relative profitability, the systems incorporating organic sources of nitrogen become more attractive. Similarly, residual nitrogen levels are also substantially lower for these systems. In table 7.15, the impacts of increased availability of nitrogen fertilizers (as might be expected in drier years) are shown. Not surprisingly, the relative profitability of the systems relying entirely on nitrogen fertilizer improves since the cost per unit of nitrogen taken up by the crop declines relative to the cost of the legume nitrogen. Also, the difference in residual nitrogen between systems is smaller when nitrogen uptake is increased.

The nitrogen content of poultry litter is also an important factor which will affect the profitability of the PL system. The results of poultry litter analyses conducted by the Virginia Tech Water Quality lab in 1988 showed an average value of 58.16 pounds of total nitrogen per ton of dry broiler litter. However, values ranged from 19.49 pounds to 82.09 pounds per ton, with a standard deviation of 14.58 tons. In table 7.16, the impacts on profitability of variations in the nitrogen content of poultry litter are shown. Each alternative value was used for the entire ten year period. Since the same mineralization rates were assumed, residual nitrogen values did not change.

Table 7.16. Impact of Different Poultry Litter Nitrogen Content Values on Present Value of Net Returns from PL System

| Nitrogen Content (lbs/ton) | PVNR |
|---|---|
| 20 | 91.74 |
| 33 | 459.11 |
| 43 | 561.99 |
| 58 | 648.86 |
| 73 | 680.40 |
| 82 | 686.37 |

At the lower end of the range of values of poultry litter nitrogen content, PVNR dropped very low. A nitrogen content of 34 pounds per ton was the point at which PVNR from the PL system dropped below PVNR from the CONV system. At a level of 43 pounds of nitrogen per ton of litter (one standard deviation below the average value) PVNR from the PL system remained substantially higher than PVNR from the CONV system.

An important consideration in terms of uncertainties associated with the nitrogen content of poultry litter is that the uncertainty is not inherent to the product. Rather, the wide range in nitrogen content results from the storage and handling of the material. For a given type of poultry, assuming a constant diet, all of the manure is of the same quality initially. However, different types and periods of storage will alter the nitrogen content, as well as the ratio of inorganic to organic nitrogen.

Variations in the nitrogen content of poultry litter do impact net returns from a system which relies on the poultry litter to satisfy crop nitrogen requirements, although total nitrogen content has to decline substantially before the PL system becomes less favorable, in terms of PVNR, than the CONV system. Nevertheless, providing farmers with accurate information on the nitrogen content of poultry litter and assuring that storage and handling practices maintain a stable product are important considerations for the successful implementation of a PL system.

Finally, differences in the mineralization or decay rates of organic nitrogen in legume green manures and livestock wastes will impact the relative profitability of the alternative systems. To examine the impact on net returns from the LWC and PL systems, the decay rate coefficients were modified. When the decay constant for the year following incorporation of the legume cover crop in the LWC system was reduced from 60 percent ot 50 percent (for the entire 10 year period), PVNR declined from $432.91 per acre to $415.74 per acre. Increasing the coefficient from 60 percent to 70 percent resulted in an increase of PVNR to $450.09.

In general, lower mineralization rates are associated with cooler and drier climate, while wetter and warmer climates will result in higher mineralization rates. To combine the impacts of changing rainfall conditions on nitrogen fertilizer availability and nitrogen mineralization from legumes, coefficients for each were changed simultaneously (for the full ten years). Simulating a higher rainfall situation, nitrogen fertilizer availability was reduced to 50 percent and legume nitrogen mineralization increased to 70 percent. As a result, PVNR from the LWC system declined to $420.67 and residual nitrogen increased from 425.8 pounds per acre to 503.9 pounds per acre over the 10 year period. For the lower rainfall scenario, nitrogen fertilizer availability was increased to 70 percent and legume nitrogen mineralization was reduced to 50 percent. The resulting PVNR increased to $441.75 and residual nitrogen declined to 356.73 pounds per acre over the 10 year period.

The impact of differences in the mineralization of organic nitrogen in poultry litter was examined by changing the decay constant for the year of application of the litter. Since reduced rates of mineralization and associated increases in the amount of poultry litter required to meet crop needs are of primary interest, only smaller decay constants were used. Reducing the decay constant from 66 percent to 56, 46 and 36 percent over the ten year period resulted in a decline in PVNR from $648.86 per acre to $611.19, $560.12, and $485.03 respectively.

Thus, accurate information on the mineralization rates for organic sources of nitrogen is an important part of nitrogen management strategies which rely on organic nitrogen. Research which better quantifies the effects of weather and climate on inorganic nitrogen fertilizer availability as well as organic nitrogen mineralization will reduce the uncertainties associated with nitrogen management.

## Summary and Conclusions

The results of this study suggest that a combination of financial incentives and education and technical assistance will be needed to change the adoption incentives for alternative production systems and the associated nitrogen management strategies. The economic analysis, combined with the physical model, reveals that several of the production systems considered will reduce residual nitrogen without reducing profits. Specifically, the split nitrogen application, alternative rotation, and poultry litter systems represent an increase in net returns as compared to the conventional system. The poultry litter system, in particular, results in substantially higher net returns. That producers in the study area are not using these systems suggests that they may have inadequate knowledge of the systems or of the benefits of using the systems. Also, in the case of the poultry litter system, poultry litter is not widely available in the study area. Thus, despite the financial incentives associated with these systems, education or technical assistance is likely needed to change producers' adoption incentives.

The legume winter cover and alternative rotation/winter cover systems represent a substantial decrease in nitrogen residuals, but PVNR declines somewhat with these systems. Financial incentives may be needed to encourage producers to use these systems. In fact, results of the sensitivity analysis show that both a nitrogen fertilizer tax and a fixed period, per acre subsidy will improve the profitability of these systems relative to the conventional system. However, results of the farmer survey and the estimation of adoption models show that factors other than profitability influence producers' decisions. Information on these systems is important for changing adoption incentives.

The value of existing and additional information on the systems is clear. Producers place a high value on accurate information from reliable sources. Thus, there is a need for additional research to assure that producers are operating with the best information and the most complete knowledge possible. Timely and comprehensive research will assure the successful implementation of the alternative systems. Increased adoption of the alternative production systems and the associated nitrogen management strategies will reduce the environmental costs of nitrogen fertilizer and increase the productivity of soils so that dependence on nitrogen fertilizers will continue to decline.

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# Appendix A.

# *Appendix A.1. Crop Production Budgets*

## TABLE A.1.a. CORN, MINIMUM TILLAGE, 100 BUSHELS PER ACRE

| Item | Unit | Price/unit | Quantity | Total |
|---|---|---|---|---|
| Seed | (unit) | 71.00 | .30 | 21.30 |
| P2O5 | (lb) | .28 | 50 | 14.00 |
| K2O | (lb) | .16 | 70 | 11.20 |
| Lime | (ton) | 24.00 | .4 | 9.60 |
| Fertilizer Application | (acre) | 4.50 | 1 | 4.50 |
| Herbicide | (acre) | 13.23 | 1 | 13.23 |
| Pesticide Application | (acre) | 5.00 | 1 | 5.00 |
| Production Machinery - variable costs | | | | |
| chisel | (acre) | 1.88 | 1X | 1.88 |
| disk | (acre) | 2.05 | 2X | 4.10 |
| plant | (acre) | 4.22 | 1X | 4.22 |
| Harvest machinery - variable costs | (acre) | 10.29 | 1X | 10.29 |
| Total | | | | 99.32 |

Source: Perkinson; Dunford et al.

TABLE A.1.b. WHEAT, CONVENTIONAL TILLAGE, 40 BUSHELS PER ACRE

| Item | Unit | Price/unit | Quantity | Total |
|---|---|---|---|---|
| Seed | (bu) | 9.50 | 2 | 19.00 |
| P2O5 | (lb) | .28 | 40 | 11.20 |
| K2O | (lb) | .16 | 80 | 12.80 |
| Lime | (ton) | 24.00 | .2 | 4.80 |
| Fertilizer Application | (acre) | 4.50 | 1 | 4.50 |
| Herbicide | (acre) | 1.60 | 1 | 1.60 |
| Pesticide Application | (acre) | 5.00 | 1 | 5.00 |
| Production Machinery - variable costs | | | | |
| chisel | (acre) | 1.88 | 1X | 1.88 |
| disk | (acre) | 2.05 | 2X | 4.10 |
| plant | (acre) | 4.13 | 1X | 4.13 |
| Harvest machinery - variable costs | (acre) | 4.07 | 1X | 4.07 |
| Total | | | | 73.08 |

Source: Perkinson; Dunford et al.

## TABLE A.1.c. BARLEY, CONVENTIONAL TILLAGE, 60 BUSHELS PER ACRE

| Item | Unit | Price/unit | Quantity | Total |
|---|---|---|---|---|
| Seed | (bu) | 4.95 | 2.5 | 12.38 |
| P2O5 | (lb) | .28 | 40 | 11.20 |
| K2O | (lb) | .16 | 80 | 12.80 |
| Lime | (ton) | 24.00 | .2 | 4.80 |
| Fertilizer Application | (acre) | 4.50 | 1 | 4.50 |
| Herbicide | (acre) | 1.60 | 1 | 1.60 |
| Pesticide Application | (acre) | 5.00 | 1 | 5.00 |
| Production Machinery - variable costs | | | | |
| chisel | (acre) | 1.88 | 1X | 1.88 |
| disk | (acre) | 2.05 | 2X | 4.10 |
| plant | (acre) | 4.13 | 1X | 4.13 |
| Harvest machinery - variable costs | (acre) | 4.07 | 1X | 4.07 |
| Total | | | | 66.46 |

Source: Perkinson; Dunford et al.

TABLE A.1.d. SOYBEANS, DOUBLE-CROP, NO-TILL, 25-30 BUSHELS PER ACRE

| Item | Unit | Price/unit | Quantity | Total |
|---|---|---|---|---|
| Seed | (bu) | 10.50 | 1 | 10.50 |
| P2O5 | (lb) | .28 | 40 | 11.20 |
| K2O | (lb) | .16 | 50 | 8.00 |
| Lime | (ton) | 24.00 | .2 | 4.80 |
| Herbicide | (acre) | 31.39 | 1 | 31.39 |
| Insecticide | (acre) | 6.70 | 1 | 6.70 |
| Pesticide Application | (acre) | 5.00 | 2 | 10.00 |
| Production Machinery - variable costs | | | | |
| plant | (acre) | 7.14 | 1X | 7.14 |
| Harvest machinery - variable costs | (acre) | 10.29 | 1X | 10.29 |
| Total | | | | 100.02 |

Source: Perkinson; Dunford et al.

TABLE A.1.e. FULL SEASON SOYBEANS, MINIMUM TILLAGE, 25-30 BUSHELS PER ACRE

| Item | Unit | Price/unit | Quantity | Total |
|---|---|---|---|---|
| Seed | (bu) | 10.50 | .67 | 7.00 |
| P2O5 | (lb) | .28 | 50 | 14.00 |
| K2O | (lb) | .16 | 70 | 11.20 |
| Lime | (ton) | 24.00 | .25 | 6.00 |
| Fertilizer Application | (acre) | 4.50 | 1 | 4.50 |
| Herbicide | (acre) | 23.31 | 1 | 23.31 |
| Insecticide | (acre) | 6.70 | 1 | 6.70 |
| Pesticide Application | (acre) | 5.00 | 1 | 5.00 |
| Production Machinery - variable costs | | | | |
| chisel | (acre) | 1.88 | 1X | 1.88 |
| disk | (acre) | 2.05 | 2X | 4.10 |
| plant | (acre) | 4.22 | 1X | 4.22 |
| Harvest machinery - variable costs | (acre) | 10.29 | 1X | 10.29 |
| Total | | | | 98.20 |

Source: Perkinson; Dunford et al.

TABLE A.1.f. WINTER COVER CROP, RYE

| Item | Unit | Price/unit | Quantity | Total |
|---|---|---|---|---|
| Seed | (bu) | 7.95 | 1.25 | 9.94 |
| Production Machinery - variable costs | | | | |
| disk - | (acre) | 2.05 | 1X | 2.05 |
| drill | (acre) | 4.13 | 1X | 4.13 |
| disk (turn under) | (acre) | 2.05 | 1X | 2.05 |
| Total | | | | 18.17 |

Source: Perkinson; Dunford et al.

## TABLE A.1.g. WINTER COVER CROP, CRIMSON CLOVER

| Item | Unit | Price/unit | Quantity | Total |
|---|---|---|---|---|
| Seed | (lb) | .58 | 22 | 12.76 |
| Production Machinery - variable costs | | | | |
| no-till drill | (acre) | 6.90 | 1X | 6.90 |
| disk (turn under) | (acre) | 2.05 | 1X | 2.05 |
| Total | | | | 21.71 |

Source: Perkinson; Dunford et al.

# *Appendix A.2. A Description of Production Systems*

## *(crops, yields, special assumptions)*

### Crop Yields

(Source: Virginia Agricultural Statistics, various years)

| YEAR | CORN | WHEAT | BARLEY | SOYBEANS |
|---|---|---|---|---|
| 1977 | 50[1] | 34 | 47.5 | 18[1] |
| 1978 | 86 | 37.5 | 52 | 28.5 |
| 1979 | 93 | 36.5 | 53 | 29.5 |
| 1980 | 50[1] | 39 | 53.5 | 14.5[1] |
| 1981 | 93 | 47 | 64 | 28.5 |
| 1982 | 118.5 | 43 | 62 | 30.5 |
| 1983 | 49[1] | 45 | 64 | 16[1] |
| 1984 | 116 | 46 | 62.5 | 28 |
| 1985 | 97.5 | 40 | 51.5 | 25.5 |
| 1986 | 49[1] | 45.5 | 56 | 23.5 |

[1] Drought years omitted as marked.

Average yields are:

| CORN | WHEAT | BARLEY | SOYBEANS |
|---|---|---|---|
| 100.67 | 41.35 | 56.6 | 27.7 |

Yields used in the analysis are:

| CORN | WHEAT | BARLEY | SOYBEANS |
|---|---|---|---|
| 100 | 40 | 60 | 25,27,30 |

## A.2.a. Conventional System Description

Rotation: Corn/Small grain - soybeans

In one acre:

Corn - .5 acre
Wheat - .275 acre
Barley - .225 acre
Soybeans - .5 acre

Composite Crop Yields (for one acre):

Corn - 100 bu/ac for .5 acres = 50 bu
Wheat - 40 bu/acre for .275 acres = 11 bu
Barley - 60 bu/acre for .225 acre = 13.5 bu
Soybeans - after wheat, 25 bu/acre for .275 acre = 6.875 bu
Soybeans - after barley, 27 bu/acre for .225 acre = 6.075 bu
Total for soybeans - 12.95 bu

Composite per Acre Variable Costs (from budgets)

| CROP | $/ACRE | ACRES | TOTAL |
|---|---|---|---|
| Corn | 99.32 | .5 | 49.66 |
| Wheat | 73.08 | .275 | 20.20 |
| Barley | 66.46 | .225 | 14.95 |
| Soybeans | 100.02 | .5 | 50.01 |
| Composite | | | 134.72 |

## A.2.b. Split Nitrogen System Description

The only change between the conventional system and the split nitrogen system is that nitrogen applications are split:

- CORN - 2 applications, one at planting and one approximately 30 days after planting.
- WHEAT/BARLEY - three applications, one at planting, one at growth stage 25-27, and one at growth stage 45.

Since all nitrogen is custom applied, and the time of application does not affect the cost, the costs of the split nitrogen system are the same as the conventional system.

## A.2.c. Non-legume Winter Cover System Description

Rotation: Corn/Small grain - soybean - rye

In one acre:

Corn - .5 acre
Wheat - .275 acre
Barley - .225 acre
Soybean - .5 acre
Rye - .5 acre

Composite Crop Yields (for one acre):

Corn - 100 bu/acre for .5 acre = 50 bu
Wheat - 40 bu/acre for .275 acre = 11 bu
Barley - 60 bu/acre for .225 acre = 13.5 bu
Soybeans - after wheat, 25 bu/acre for .275 acre = 6.875 bu
Soybeans - after barley, 27 bu/acre for .225 acre = 6.075 bu
Total for soybeans - 12.95 bu

Composite per Acre Variable Costs (from budgets)

| CROP | $/ACRE | ACRES | TOTAL |
|---|---|---|---|
| Corn | 99.32 | .5 | 49.66 |
| Wheat | 73.08 | .275 | 20.10 |
| Barley | 66.46 | .225 | 14.95 |
| Soybeans | 100.02 | .5 | 50.01 |
| Rye | 18.17 | .5 | 9.09 |
| Composite | | | 143.81 |

## A.2.d. Legume Winter Cover System Description

Rotation: Corn/Small grain - soybeans - crimson clover

Assumptions:

- Earlier soybean variety used to allow seeding of clover by mid-September.
- Yield penalty for soybeans of 10 percent.

Composite Crop Yields (for one acre):

| | |
|---|---|
| Corn | 50 bu |
| Wheat | 11 bu |
| Barley | 13.5 bu |
| Soybeans | (12.95).10 = 11.66 bu |

Composite per Acre Variable Costs (from budgets)

| CROP | $/ACRE | ACRES | TOTAL |
|---|---|---|---|
| Corn | 99.32 | .5 | 49.66 |
| Wheat | 73.08 | .275 | 20.10 |
| Barley | 66.46 | .225 | 14.95 |
| Soybeans | 100.02 | .5 | 50.01 |
| Crimson clover | 21.71 | .5 | 10.86 |
| Composite | | | 145.58 |

## A.2.e. Alternative Rotation System Description

Rotation: Corn/Small grain - soybeans/Soybeans/Small grain - soybeans

In one acre:

Corn - .25 acre
Wheat - .275 acre
Barley - .225 acre
Full season soybean - .25 acre
Double crop soybean - .5 acre

Composite Crop Yields (for one acre):

Corn - 100 bu/acre for .25 acre = 25 bu
Wheat - 40 bu/acre for .275 acre = 11 bu
Barley - 60 bu/acre for .225 acre = 13.5 bu
Full season soybean - 30 bu/acre for .25 acre = 7.5 bu
Double crop soybean - after wheat, 25 bu/acre for .275 acre = 6.875 bu
Double crop soybean - after barley, 27 bu/acre for .225 acre = 6.075 bu
Total for soybeans - 20.45 bu

Composite per Acre Variable Costs (from budgets)

| CROP | $/ACRE | ACRES | TOTAL |
|---|---|---|---|
| Corn | 99.32 | .25 | 24.83 |
| Wheat | 73.08 | .275 | 20.10 |
| Barley | 66.46 | .225 | 14.95 |
| Full season soybean | 98.20 | .25 | 24.55 |
| Double crop soybean | 100.02 | .5 | 50.01 |
| Composite | | | 134.44 |

## A.2.f. Alternative Rotation/Winter Cover System Description

Rotation: Corn/Small grain - soybeans - rye/Soybeans/Small grain - soybeans - crimson clover

Assumptions:

- Early soybean variety is used for double crop soybeans.
- A 10 percent yield penalty for double crop soybeans is assumed.

In one acre:

Corn - .25 acre
Wheat - .275 acre
Barley - .225 acre
Full season soybean - .25 acre
Double crop soybean - .5 acre
Rye - .25 acre
Crimson clover - .25 acre

Composite Crop Yields (for one acre):

Corn - 25 bu
Wheat - 11 bu
Barley - 13.5 bu
Full season soybean - 7.5 bu
Double crop soybean - (12.95 bu).10 $\doteq$ 11.66 bu
Total for soybeans - 19.16 bu

Composite per Acre Variable Costs (from budgets)

| CROP | $/ACRE | ACRES | TOTAL |
|---|---|---|---|
| Corn | 99.32 | .25 | 24.83 |
| Wheat | 73.08 | .275 | 20.10 |
| Barley | 66.46 | .225 | 14.95 |
| Full season soybean | 98.20 | .25 | 24.55 |
| Double crop soybean | 100.02 | .5 | 50.01 |
| Rye | 18.17 | .25 | 4.59 |
| Crimson clover | 21.71 | .25 | 5.43 |
| Composite | | | 144.42 |

## A.2.g. Poultry Litter System Description

Rotation: Corn/Small grain - soybeans

In one acre:

Corn - .5 acre
Wheat - .275 avre
Barley - .225 acre
Soybean - .5 acre

Composite Crop Yields (for one acre):

Corn - 100 bu/acre for .5 acre = 50 bu
Wheat - 40 bu/acre for .275 acre = 11 bu
Barley - 60 bu/acre for .225 acre = 13.5 bu
Soybeans - after wheat, 25 bu/acre for .275 acre = 6.875 bu
Soybeans - after barley, 27 bu/acre for .225 acre = 6.075 bu
Total for soybeans - 12.95 bu

To calculate per acre variable costs, use the crop budgets from A.1 but remove the costs of $P_2O_5$ and $K_2O$.

| CROP | $/ACRE | P&K COST | NEW $/ACRE | ACRES | TOTAL |
|---|---|---|---|---|---|
| Corn | 99.32 | 25.20 | 74.12 | .5 | 37.06 |
| Wheat | 73.08 | 24.00 | 49.08 | .275 | 13.50 |
| Barley | 66.46 | 24.00 | 42.46 | .225 | 9.55 |
| Soybeans | 100.02 | 19.20 | 80.82 | .5 | 40.41 |
| Composite | | | | | 100.52 |

Add in the cost of spreading the litter on the field, using a truck mounted spreader:

| | |
|---|---|
| truck | $13.62/hour |
| spreader | 3.16/hour |
| total | 16.78/hour |

At an average speed of five miles per hour, covering a 12 foot row in each pass, machine will cover one acre in .1383 hours. At a 65 percent efficiency rate (allowing for refilling the spreader, etc.):

.2128 hours/acre X $16.78/hour = $3.57/acre

So, the composite per acre variable costs = $100.52 + $3.57 = $104.09.

# *Appendix A.3. Crop Prices*

Using the basis formula and the basis figures from Kenyon's Virginia Basis Tables for Corn, Soybeans, Wheat and Soybean Meal: Cash price = Futures price + Basis.

For corn: Northern Neck corn basis for September contract during September is + 1. The Chicago Board of Trade futures price for September corn on April 4, 1988 was 219.25 cents (Source: Wall Street Journal, April 4, 1988). So, cash price = 2.19 + .01 = 2.20.

For wheat: Richmond wheat basis for July contract during June is -11. The Chicago Board of Trade futures price for July wheat on September 15, 1987 was 282.75 cents (Source: Wall Street Journal, September 15, 1987). So, cash price = 2.83 - .11 = 2.73.

For soybeans: A futures + basis approach was not used since high futures prices reflected drought conditions. Instead, an historical average price was used. From Virginia Agricultural Statistics (various years), Virginia state average soybean prices were:

| YEAR | PRICE |
|---|---|
| 1977 | 5.80 |
| 1978 | 6.85 |
| 1979 | 6.28 |
| 1980 | 7.89 |
| 1981 | 6.09 |
| 1982 | 5.70 |
| 1983 | 7.85 |
| 1984 | 5.94 |
| 1985 | 5.15 |
| 1986 | 4.85 |
| Ten Year Average | 6.24 |

For barley: Since a futures contract for barley is not offered in the United States, an historical price series was also used to calculate an average price for barley. (Virginia state average prices, Virginia Agricultural Statistics, various issues).

| | |
|---|---|
| 1977 | 1.85 |
| 1978 | 1.85 |
| 1979 | 1.80 |
| 1980 | 2.26 |
| 1981 | 2.09 |
| 1982 | 1.90 |
| 1983 | 2.05 |
| 1984 | 2.35 |
| 1985 | 1.70 |
| 1986 | 1.50 |
| Ten Year Average | 1.94 |

# *Appendix A.4. Labor Constraints*

The following calculations are based on the reported "Average Number of Days Suitable for Fieldwork (Five year average, 1982-86)" from Virginia Agricultural Statistics, 1977.

Full Time Farmer

| MONTH | DAYS | HOURS/DAY (ASSUMED) | HOURS/MONTH |
|---|---|---|---|
| March[1] | 15.3 | 10 | 153 |
| April | 15.3 | 10 | 153 |
| May | 18.1 | 10 | 181 |
| June | 22.6 | 11 | 249 |
| September | 26.1 | 11 | 287 |
| October | 18.5 | 10 | 185 |
| November | 18.9 | 10 | 189 |

[1] The number of days for March was not reported, so the April figure was used.

For part-time farmers, it was assumed that 40 hours per week were worked off the farm, or eight hours per day, 5 days per week.

In March, a full-time farmer has 7 days X 4 weeks X 10 hours or 280 hours available. A part-time farmer has:

(5 days X 4 weeks X 2 hours) + (2 days X 4 weeks X 10 hours) = 120 hours available.

Comparing the time available for the full- and part-time farmer,

120 = .43(280).

So, in March, a part-time farmer has 43 percent of the time a full time farmer has available for field work. If the full-time farmer has 153 field hours available, then the part-time farmer has 65.8 field hours available.

This calculation is made for each month and presented in table A.4.

Table A.4. Part-time Farmer Labor Constraints

| Month | #1 Hours of Daylight | #2 Hours Left After Work | #3 Field Days | #4 Percent of Full Time | #5 Labor Hours Available |
|---|---|---|---|---|---|
| March | 10 | 2 | 15.3 | .43 | 65.8 |
| April | 10 | 2 | 15.3 | .43 | 65.8 |
| May | 10 | 2 | 18.1 | .43 | 77.8 |
| June | 11 | 3 | 22.6 | .48 | 119.3 |
| September | 11 | 3 | 26.1 | .48 | 137.8 |
| October | 10 | 2 | 18.5 | .43 | 79.6 |
| November | 10 | 2 | 18.9 | .43 | 81.3 |

Calculations:

$$\#4 = \frac{(\#1(2)(4)) + (\#2(5)(4))}{(\#1(7)(4))}$$

$$\#5 = \#4(\#1)(\#3)$$

# *Appendix A.5. Field hours required for each system*

## Hours per Acre Required for Field Operations

For minimum tillage corn and minimum tillage full-season soybeans:

| TILLAGE OPERATION | HOURS/ACRE |
|---|---|
| chisel plow | .2717 |
| disk (2X) | .5236 |
| plant | .3058 |
| | 1.1011 |
| combine | .5291 |

For conventional tillage small grain:

| TILLAGE OPERATION | HOURS/ACRE |
|---|---|
| chisel plow | .2717 |
| disk (2x) | .5236 |
| plant | .3817 |
| | 1.177 |
| combine | .2646 |

For no-till double crop soybeans:

| TILLAGE OPERATION | HOURS/ACRE |
|---|---|
| plant | .4587 |
| combine | .5291 |

For rye:

| TILLAGE OPERATION | HOURS/ACRE |
|---|---|
| disk (1X) | .2618 |
| plant | .3817 |
| | .6435 |
| disk under | .2618 |

For crimson clover:

| TILLAGE OPERATION | HOURS/ACRE |
|---|---|
| plant (no-till) | .5025 |
| disk under | .2618 |

## A.5.a. Conventional System Field Operation Hours

| MONTH | OPERATION | FIELD HOURS REQUIRED | ACREAGE | FIELD HOURS PER ACRE[1] |
|---|---|---|---|---|
| April | Plant corn | 1.1011 | .5 | .6056 |
| June | Combine barley, wheat | .2646 | .5 | |
| | Plant soybeans | .4587 | .5 | .3978 |
| September | Combine corn | .5291 | .5 | .2910 |
| October | Plant barley, wheat | 1.177 | .5 | .6474 |
| November | Combine soybeans | .5291 | .5 | .2910 |

[1] Field hours per acre include an additional 10 percent efficiency allowance.

## A.5.b. Split Nitrogen System Field Operation Hours

Field hours, per month, are the same as with the conventional system.

## A.5.c. Non-legume Winter Cover System Field Operation Hours

| MONTH | OPERATION | FIELD HOURS REQUIRED | ACREAGE | FIELD HOURS PER ACRE[1] |
|---|---|---|---|---|
| April | Disk under rye | .2618 | .5 | |
| | Plant corn | 1.1011 | .5 | .7496 |
| June | Combine barley, wheat | .2646 | .5 | |
| | Plant soybeans | .4587 | .5 | .3979 |
| September | Combine corn | .5291 | .5 | |
| | Plant barley | 1.177 | .225 | .5823 |
| October | Plant wheat | 1.177 | .275 | |
| | combine soybeans | .5291 | .5 | |
| | Seed rye | .6435 | .5 | 1.001 |

[1] Field hours per acre include an additional 10 percent efficiency allowance.

## A.5.d. Legume Winter Cover System Field Operation Hours

| MONTH | OPERATION | FIELD HOURS REQUIRED | ACREAGE | FIELD HOURS PER ACRE[1] |
|---|---|---|---|---|
| March | Disk under clover | .2618 | .5 | .1440 |
| April | Plant corn | 1.1011 | .5 | .6056 |
| June | Combine barley, wheat | .2646 | .5 | |
| | Plant soybeans | .4587 | .5 | .3979 |
| September | Combine soybeans | .5291 | .5 | |
| | Seed clover | .5025 | .5 | |
| | Combine corn | .5291 | .5 | .8584 |
| October | Plant barley, wheat | 1.177 | .5 | .6474 |

[1] Field hours per acre include an additional 10 percent efficiency allowance.

## A.5.e. Alternative Rotation Field Operation Hours

| MONTH | OPERATION | FIELD HOURS REQUIRED | ACREAGE | FIELD HOURS PER ACRE[1] |
|---|---|---|---|---|
| April | Plant corn | 1.1011 | .25 | .3028 |
| May | Plant full season soybean | 1.1011 | .25 | .3028 |
| June | Combine barley, wheat | .2646 | .5 | |
| | Plant double crop soybean | .4587 | .5 | .3979 |
| September | Combine corn | .5291 | .25 | .1455 |
| October | Plant barley, wheat | 1.177 | .5 | |
| | Cut full season soybean | .5291 | .25 | .7929 |
| November | Cut double crop soybean | .5291 | .5 | .2910 |

[1] Field hours per acre include an additional 10 percent efficiency allowance.

## A.5.f. Alternative Rotation/Winter Cover Field Operation Hours

| MONTH | OPERATION | FIELD HOURS REQUIRED | ACREAGE | FIELD HOURS PER ACRE[1] |
|---|---|---|---|---|
| March | Disk under clover | .2618 | .25 | .0720 |
| April | Disk under rye | .2618 | .25 | |
| | Plant corn | 1.1011 | .25 | .3748 |
| May | Plant full season soybean | 1.1011 | .25 | .3028 |
| June | Combine barley, wheat | .2646 | .5 | |
| | Plant double crop soybean | .4587 | .5 | .3979 |
| September | Combine corn | .5291 | .25 | |
| | Cut double crop soybean | .5291 | .25 | |
| | Seed clover | .5025 | .25 | .4292 |
| October | Cut double crop soybean | .5291 | .25 | |
| | Seed rye | .6435 | .25 | |
| | Plant barley, wheat | 1.177 | .5 | .9699 |
| November | Cut full season soybean | .5291 | .25 | .1455 |

[1] Field hours per acre include an additional 10 percent efficiency allowance.

## A.5.g. Poultry Litter System Field Operation Hours

| MONTH | OPERATION | FIELD HOURS REQUIRED | ACREAGE | FIELD HOURS PER ACRE[1] |
|---|---|---|---|---|
| April | Spread litter | .2128 | .5 | |
| | Plant corn | 1.1011 | .5 | .7226 |
| June | Combine barley, wheat | .2646 | .5 | |
| | Plant soybeans | .4587 | .5 | .3979 |
| September | Combine corn | .5291 | .5 | .2910 |
| October | Spread litter | .2128 | .5 | |
| | Plant barley, wheat | 1.177 | .5 | .7644 |
| November | Combine soybeans | .5291 | .5 | .2910 |

[1] Field hours per acre include an additional 10 percent efficiency allowance.

# *Appendix A.6. Cost to producer for poultry litter at delivery*

Assume the poultry litter broker pays the following:

| | |
|---|---|
| To purchase litter from poultry producer | $5.00/ton |
| To rent front end loader and load litter | $1.50/ton |
| To transport litter | $12.75/ton |
| Broker pays | $19.25 |
| Profit margin for broker | $1.00/ton |
| Total cost to producer for litter at delivery | $20.25 |

Source: Davis, Weaver et al.

Calculation of costs to transport litter:

- Assume $1.50 per loaded mile.
- 170 miles from Harrisonburg, VA to Tappahannock, VA
- Transport by a 20 ton capacity truck
- 1.50/mile X 170 miles / 20 tons = $12.75/ton

# Appendix B.

# *Appendix B.1. Nitrogen Mineralization from Soil Organic Matter*

Soils in eastern Virginia contain about one percent organic matter (Donahue). From the Soil Survey of Richmond County Virginia, 60 percent of the soil in the county has an average organic matter content of 1.19 percent. From the Soil Survey of Westmoreland County of Virginia, 53.9 percent of the soil in the county has an average organic matter content of 1.16 percent.

From Ankerman and Large, Soil and Plant Analysis, pages 6 and 66, a seven inch plow layer on one acre of land has an average weight of 2,000,000 pounds. If the soil has one percent organic matter, then that acre contains 20,000 pounds of organic matter. Generally, soil organic matter contains five percent nitrogen - that is 1,000 pounds for this soil. On average, 2 - 4 percent of this nitrogen becomes available to plants during the growing season. If an average of 3 percent is assumed, 30 pounds per acre of available nitrogen is mineralized in a one percent organic matter soil.

This value, 30 pounds per acre, is used as the value of *sn* in the nitrogen model.

# *Appendix B.2. Nitrogen Content of Grain Crops*

| CROP | YIELD PER ACRE |  | NITROGEN CONTENT | PERCENTAGE NITROGEN | SOURCE |
|---|---|---|---|---|---|
|  | tons | bushels | (lbs/ac) |  |  |
| Corn (grain) | 4.2 | 150 | 135 | 1.61 | Gilbertson et al. |
| Corn (stover) | 4.5 |  | 100 | 1.11 |  |
| Corn (grain) | 4.2 | 150 | 135 | 1.61 | Tisdale & Nelson |
| Corn (stover) | 3.15 |  | 65 | 1.03 |  |
| Corn (grain) | 4.2 | 150 | 135 | 1.62 | Donahue et al. |
| Corn (stover) | 4.5 |  | 100 | 1.11 |  |
| Wheat (grain) | 1.2 | 40 | 50 | 2.08 | Gilbertson et al. |
| Wheat (straw) | 1.5 |  | 20 | .67 |  |
| Wheat (grain) | 3 | 60 | 75 | 2.08 | Tisdale & Nelson |
| Wheat (straw) | 2.7 |  | 50 | .93 |  |
| Wheat (grain) | 2.4 | 80 | 100 | 2.08 | Donahue et al. |
| Wheat (straw) | 2 |  | 34 | .85 |  |
| Barley (grain) | .96 | 40 | 35 | 1.82 | Gilbertson et al. |
| Barley (straw) | 1 |  | 15 | .75 |  |
| Barley (grain) | 2.4 |  | 110 | 2.29 | Tisdale & Nelson |
| Barley (grain) | 1.92 | 80 | 70 | 1.82 | Donahue et al. |
| Barley (straw) | 2 |  | 30 | .75 |  |
| Soybeans (grain) | 1.2 | 40 | 150 | 6.25 | Gilbertson et al. |
| Soybeans (grain) | 1.5 | 50 | 160 | 5.3 | Tisdale & Nelson |
| Soybeans (straw) | 1.1 |  | 25 | 1.14 |  |
| Soybeans (grain) | 1.2 | 40 | 150 | 6.25 | Donahue et al. |
| Soybeans (straw) | 2.8 |  | 30 | .54 |  |

Total (above ground) biomass of plant (lbs) = Grain (lbs) + Straw (lbs).

The values used for nitrogen content of crops are:

| | |
|---|---|
| Corn | 1.6 percent nitrogen in grain<br>1.35 percent nitrogen in total biomass |
| Wheat | 2.08 percent nitrogen in grain<br>1.52 percent nitrogen in total biomass |
| Barley | 1.82 percent nitrogen in grain<br>1.28 percent nitrogen in total biomass |
| Soybeans | 6.25 percent nitrogen in grain<br>2.75 percent nitrogen in total biomass |

Harvest Index = Grain weight/Total biomass (Source: Shibles et al.)

Corn harvest index:

| | |
|---|---|
| Gilbertson et al. | .4828 |
| Tisdale and Nelson | .5714 |
| Donahue et al. | .4828 |
| Brann | .55[1] |

Wheat harvest index:

| | |
|---|---|
| Gilbertson et al | .4444 |
| Tisdale and Nelson | .5263 |
| Donahue et al. | .5455 |
| Brann | .55[1] |

Barley harvest index:

| | |
|---|---|
| Gilbertson et al. | .4898 |
| Donahue et al. | .4898 |
| Brann | .5[1] |

Soybean harvest index:

| | |
|---|---|
| Tisdale and Nelson | .5769 |
| Donahue et al. | .3 |
| Shibles et al. | .3[1] |

---

[1] These are the values assumed in calculations.

To calculate nitrogen content of crops at assumed yields:

For corn - (corn yield (bu/ac) X 56 lbs/bu)/.55 = total biomass weight
Total biomass X .0135 = Total nitrogen in crop
Crop yield (lbs/ac) X .016 = nitrogen in grain

E.G. for 100 bu/ac:

(100 bu/ac X 56 lbs/bu)/.55 = 10,182 lbs. biomass
10,182 lbs X .0135 = 138 lbs nitrogen in crop
5600 lbs/ac X .016 = 90 lbs nitrogen in grain (48 lbs in stover)

For wheat - (wheat yield (bu/ac) X 60 lbs/bu)/.55 = total biomass weight
Total biomass X .0152 = Total nitrogen in crop
Crop yield (lbs/ac) X .0208 = nitrogen in grain

E.G. for 40 bu/ac:

(40 bu/ac X 60 lbs/bu)/.55 = 4364 lbs. biomass
4364 lbs X .0152 = 67 lbs nitrogen in crop
2400 lbs/ac X .0208= 50 lbs nitrogen in grain (17 lbs in straw)

For barley - (barley yield (bu/ac) X 48 lbs/bu)/.50 = total biomass weight
Total biomass X .0128 = Total nitrogen in crop
Crop yield (lbs/ac) X .0182 = nitrogen in grain

E.G. for 60 bu/ac:

(60 bu/ac X 48 lbs/bu)/.50 = 5760 lbs. biomass
5760 lbs X .0128 = 74 lbs nitrogen in crop
2880 lbs/ac X .0182= 52 lbs nitrogen in grain (22 lbs in straw)

For soybeans - (soybean yield (bu/ac) X 60 lbs/bu)/.30 = total biomass weight
Total biomass X .0275 = Total nitrogen in crop
Crop yield (lbs/ac) X .0625 = nitrogen in grain

E.G. for 25.9 bu/ac:

(25.9 bu/ac X 60 lbs/bu)/.30 = 5180 lbs. biomass
5180 lbs X .0275 = 143 lbs nitrogen in crop
1554 lbs/ac X .0625= 97 lbs nitrogen in grain (46 lbs in straw)

NOTE: soybeans get 74 percent of nitrogen requirement through symbiotic fixation (Shibles et al.)

# *Appendix B.3. Nitrogen Budgets for Production Systems*

## B.3.a. Conventional System Nitrogen Budget

| CROP | ACREAGE | YIELD | N UPTAKE | COMPOSITE UPTAKE |
|---|---|---|---|---|
| Corn | .5 | 100 | 138 | 69.0 |
| Wheat | .275 | 40 | 67 | 18.43 |
| Barley | .225 | 60 | 74 | 16.65 |
| Soybeans | .5 | 25.9 | 143 | 71.5 |
| Total uptake | | | | 175.6 |

| CROP | NITROGEN UPTAKE | NITROGEN IN GRAIN | NITROGEN IN STUBBLE | NITROGEN FIXED |
|---|---|---|---|---|
| Corn | 69.0 | 45.0 | 24.0 | |
| Wheat | 18.43 | 13.75 | 4.68 | |
| Barley | 16.65 | 11.7 | 4.95 | |
| Soybeans | 71.5 | 48.5 | 23.0 | 52.9 |
| Totals | 175.6(*NR*) | 118.95 | 56.6(*rn*) | 52.9(*fn*) |

## B.3.b. Split Nitrogen System

The values for *NR, rn* and *fn* are the same as in the conventional system.

## B.3.c. Non-legume Winter Cover System

The values for *NR* and *fn* are the same as in the conventional system. To calculate *rn*:

> The rye cover, if left to mature, would yield, on average, 26 bushels per acre (Virginia Agricultural Statistics) and have a total nitrogen content of 40 pounds per acre. If the rye is plowed under in early April, it will have taken up 50-55 percent of the total nitrogen it would take up by maturity (assuming it follows the pattern of uptake followed by wheat, as shown in Alley et al.) or 20 lb/ac of nitrogen.
>
> Since one-half acre of rye is planted, rye contains 10 lbs/acre of nitrogen when it is plowed under. Therefore, *rn* equals 56.6 + 10 = 66.6 lbs/acre.

## B.3.d. Legume Winter Cover System

| CROP | ACREAGE | YIELD | N UPTAKE | COMPOSITE UPTAKE |
|---|---|---|---|---|
| Corn | .5 | 100 | 138 | 69.0 |
| Wheat | .275 | 40 | 67 | 18.43 |
| Barley | .225 | 60 | 74 | 16.65 |
| Soybeans | .5 | 23.3 | 129 | 64.5 |
| Total uptake | | | | 168.6 |

| CROP | NITROGEN UPTAKE | NITROGEN IN GRAIN | NITROGEN IN STUBBLE | NITROGEN FIXED |
|---|---|---|---|---|
| Corn | 69.0 | 45.0 | 24.0 | |
| Wheat | 18.43 | 13.75 | 4.68 | |
| Barley | 16.65 | 11.7 | 4.95 | |
| Soybeans | 64.5 | 43.7 | 20.8 | 47.7 |
| Totals | 168.6(*NR*) | 115.15 | 54.4(*rn*) | 47.7(*fn*) |

To calculate nitrogen from crimson clover cover:

> Assume a good clover stand contains 100 lbs/acre of nitrogen (fixed + uptake from soil). On one-half acre, clover contains 50 lbs/acre of nitrogen. This is the value used for *ln*.

This information comes from the following sources:

> Hargrove - Legumes provide equivalent of 100 lbs/acre of nitrogen.
> Wagger - Crimson clover plowed under on April 17 contained 101 lbs/acre of nitrogen.
> LaRue and Patterson; Power - Nitrogen fixed by clovers ranges from 70 to 200 lbs/acre.

## B.3.e. Alternative Rotation

| CROP | ACREAGE | YIELD | N UPTAKE | COMPOSITE UPTAKE |
|---|---|---|---|---|
| Corn | .25 | 100 | 138 | 34.5 |
| Wheat | .275 | 40 | 67 | 18.43 |
| Barley | .225 | 60 | 74 | 16.65 |
| Soybeans (dc) | .5 | 25.9 | 143 | 71.5 |
| Soybeans (fs) | .25 | 30 | 165 | 41.25 |
| Total uptake | | | | 182.3 |

| CROP | NITROGEN UPTAKE | NITROGEN IN GRAIN | NITROGEN IN STUBBLE | NITROGEN FIXED |
|---|---|---|---|---|
| Corn | 34.5 | 22.5 | 12.0 | |
| Wheat | 18.43 | 13.75 | 4.68 | |
| Barley | 16.65 | 11.7 | 4.95 | |
| Soybeans (dc) | 71.5 | 48.5 | 23.0 | 52.9 |
| Soybeans (fs) | 41.25 | 28.13 | 13.12 | 30.5 |
| Totals | 182.3(*NR*) | 124.58 | 57.8(*rn*) | 83.4(*fn*) |

## B.3.f. Alternative Rotation/Winter Cover

| CROP | ACREAGE | YIELD | N UPTAKE | COMPOSITE UPTAKE |
|---|---|---|---|---|
| Corn | .25 | 100 | 138 | 34.5 |
| Wheat | .275 | 40 | 67 | 18.43 |
| Barley | .225 | 60 | 74 | 16.65 |
| Soybeans (dc) | .5 | 23.3 | 129 | 64.5 |
| Soybeans (fs) | .25 | 30 | 165 | 41.25 |
| Total uptake | 175.3 | | | |

| CROP | NITROGEN UPTAKE | NITROGEN IN GRAIN | NITROGEN IN STUBBLE | NITROGEN FIXED |
|---|---|---|---|---|
| Corn | 34.5 | 22.5 | 12.0 | |
| Wheat | 18.43 | 13.75 | 4.68 | |
| Barley | 16.65 | 11.7 | 4.95 | |
| Soybeans (dc) | 64.5 | 43.7 | 20.8 | 47.7 |
| Soybeans (fs) | 41.25 | 28.13 | 13.12 | 30.5 |
| Totals | 175.3(*NR*) | 119.78 | 55.6 | 78.2(*fn*) |

To calculate *rn*:

> Rye cover crop is on .25 acres, contains 20 lbs/acre of nitrogen, so adds 5 lbs/acre of nitrogen. Therefore, $55.6 + 5 = 60.5 = rn$.

To calculate *ln*:

> The clover is planted on .25 acres. At 100 lbs/acre for the nitrogen content of the clover, *ln* equals 25 lbs/acre.

Sources: Hargrove; LaRue and Patterson; Power.

## B.3.g. Poultry Litter System

For this system, *NR*, *rn* and *fn* are all the same value as for the conventional system.

# *Appendix B.4. Nutrient Content of Poultry Litter*

From the Department of Agricultural Engineering manure tests in 1988, for dry broiler litter, based on 73 observations:

| | per ton of litter |
|---|---|
| Total Nitrogen | 58.16 lbs. ± 14.58 lbs. |
| $P_2O_5$ | 40.67 lbs. ± 22.59 lbs. |
| $K_2O$ | 30.27 lbs ± 10.25 lbs. |

From Givens, broiler litter averages 40 percent inorganic nitrogen and 60 percent organic nitrogen.

# *Appendix B.5. Estimation of Nitrogen Carryover (Decay Rates)*

## B.5.a. Immobilization of Inorganic Nitrogen

Generally, 20 to 35 percent of applied inorganic nitrogen is immobilized. Approximately 5 to 15 percent of that amount will be mineralized the following year (Keeney, 1986; Bartholomew).

For soils with low organic matter content, net immobilization is low (Nommik).

Assume 20 percent is immobilized, and 10 percent of that is mineralized the following year.

(.20).10 = .02 or 2 percent = $h$ in nitrogen model.

## B.5.b. Conventional System

Of the inorganic nitrogen applied:

| | |
|---|---|
| 60% | to current crop ($p$ in nitrogen model) |
| 2% | immobilized and used next year ($h$ in nitrogen model) |
| 15% | incorporated in permanent soil organic matter |
| 77% | |
| 23% | to nitrogen residual ($x$ in nitrogen model) |
| 100% | |

For the 56.6 lbs/ac of nitrogen in crop residues, the decay rate is .15, .05, .03 ($pr$ in nitrogen model). This is calculated as follows:

> From Va Tech Soil Testing and Plant Analysis Laboratory Procedures, an average soybean yield (25 - 30 bu/acre) will provide 15 lbs/acre of nitrogen to next year's crop. Corn and small grain stubble will decay little to none the first year and a small amount in subsequent years (Martin et al.; Bartholomew).
>
> 15 lbs/acre of nitrogen for .5 acre = 7.5 lbs/acre = 13.25% of 56.6.
>
> Adding in a small amount for corn and wheat stubble, the decay rate is calculated as 15% in the first year, 5% in the second year and 3% in the third year. The 5% and 3% are based on decay rates for other types of organic material, since most organic residues have essentially the same decay rates in later periods (Reneau). Refer to decay rates for manures (Gilbertson et al.).

Of the residue nitrogen, 15% goes to permanent soil organic matter. This leaves 62% which goes to residual nitrogen ($x$ in nitrogen model).

## B.5.c Split Nitrogen System

Of the inorganic nitrogen applied:

| | |
|---|---|
| 80% | to current crop (*p* in nitrogen model) |
| 2% | immobilized and used next year (*h* in nitrogen model) |
| 10% | incorporated in permanent soil organic matter |
| 92% | |
| 8% | to nitrogen residual (*x* in nitrogen model) |
| 100% | |

Assume:

The amount of applied nitrogen which is used by the plant is increase when application is timed more closely to crop needs (Alley et al.)

A smaller total amount is immobilized since application more closely coincides with crop use and a smaller amount of inorganic nitrogen is in the soil at any given time.

The crop residue nitrogen decay rate (*pr*) is the same as in the conventional system.

## B.5.d. Non-legume Winter Cover System

Of the inorganic nitrogen applied:

| | |
|---|---|
| 60% | to current crop (*p* in nitrogen model) |
| 2% | immobilized and used next year (*h* in nitrogen model) |
| 10% | to permanent organic matter |
| 10% | to rye cover crop |
| 82% | |
| 18% | to nitrogen residual (*x* in nitrogen model) |
| 100% | |

Calculation of crop residue nitrogen decay:

56.6 lbs/ac (crops) + 10 lbs/ac (rye) = 66.6 lbs/acre

| Year of decay | Crop residue | Rye residue | Total |
|---|---|---|---|
| 1 | .15 | .6 | .22 |
| 2 | .05 | .1 | .06 |
| 3 | .03 | .1 | .04 |
| 4 | | .05 | .008 |

The decay rate for the rye is based on Allison, Pieters and McKee, and Bartholomew, and it is assumed that the rye cover is turned under in March. Of the crop residue nitrogen, 15% goes to permanent soil organic matter. That leaves 52.2% which goes to residual nitrogen (*x*).

### B.5.e Legume Winter Cover System

Of the inorganic nitrogen applied:

| | |
|---|---|
| 60% | to current crop (*p*) |
| 2% | immobilized and used next year (*h*) |
| 10% | to permanent soil organic matter |
| 15% | to crimson clover |
| 87% | |
| 13% | to nitrogen residual (*x*) |
| 100% | |

The decay rate for crop residue nitrogen (*pr*) is .15, .05, .03. 15% goes to permanent soil organic matter. That leaves 62% which goes to residual nitrogen (*x*).

The decay rate for the legume cover crop nitrogen (*pl*) is .6, .1, .1, .05. 15% goes to permanent soil organic matter. The decay rate is based on Bartholomew. For later periods, refer to Gilbertson et al.

### B.5.f. Alternative Rotation

Of the inorganic nitrogen applied:

| | |
|---|---|
| 60% | to current crop (*p*) |
| 2% | immobilized and used next year (*h*) |
| 15% | to permanent soil organic matter |
| 77% | |
| 23% | to nitrogen residual (*x*) |
| 100% | |

The decay rate for crop residue nitrogen (*pr*) is .2, .05, .03. 15% goes to permanent soil organic matter. That leaves 57%, which goes to residual nitrogen (*x*).

The decay rate is based on an average soybean yield (25 - 30 bu/ac) and a contribution of 15 lbs/acre of nitrogen to next year's crop (VA Tech Soil Test Guide).

15 lbs/acre X .75 acres = 11.25 lbs/acre of nitrogen

11.25 lbs = 19% of 57.8 lbs in residue

20% is used to allow for corn and small grain stubble. Refer to Gilbertson et al. for later years.

## B.5.g. Alternative Rotation/Winter Cover

Of the inorganic nitrogen applied:

| | |
|---|---|
| 60% | to current crop (*p*) |
| 2% | immobilized and used next year (*h*) |
| 10% | to permanent soil organic matter |
| 10% | to cover crops |
| 82% | |
| 18% | to nitrogen residual (*x*) |
| 100% | |

The decay rate for crop residue nitrogen (*pr*) is .19, .05, .04, and is calculated by:

| Year of decay | Crop residue | Rye residue | Total |
|---|---|---|---|
| 1 | .15 | .6 | .19 |
| 2 | .05 | .1 | .05 |
| 3 | .03 | .1 | .04 |
| 4 | | .05 | |

15% goes to permanent soil organic matter. That leaves 57% which goes to residual nitrogen (*x*).

The decay rate for the clover cover crop nitrogen is .6, .1, .1, .05. 15% goes to permanent soil organic matter.

# *Appendix B.6. Poultry Litter Nitrogen Content and Decay Rate*

From appendix B.4.:

1 ton litter = 58 lbs of nitrogen

40% inorganic = 23 lbs

60% organic = 35 lbs

From Givens:

Nitrogen availability from litter, with immediate incorporation, is 90% of inorganic in year 1, 50% of organic in year 1, 12% of organic in year 2, 5 percent of organic in year 3, 2 percent of organic in year 4 and 2 percent of organic in year 5.

Of total nitrogen, then, availability is:

| | | | |
|---|---|---|---|
| Year 1 | 23(.9) + 35(.5) | = 38.2 = | 66% |
| Year 2 | 35(.12) | = 4.2 = | 7.2% |
| Year 3 | 35(.05) | = 1.65= | 3% |
| Year 4 | 35(.02) | = .7 = | 1.2% |
| Year 5 | 35(.02) | = .7 = | 1.2% |
| TOTAL | | | 78.6% |

The decay rate for poultry litter nitrogen (*pp*), then, is .66, .072, .03, .012, .012. 15% goes to permanent soil organic matter. That leaves 6.4% which goes to residual nitrogen (*x*).

The decay rate for crop residue nitrogen (*pr*) is .15, .05, .03. 15% goes to permanent soil organic matter, and 62% goes to residual nitrogen (*x*).

# Appendix C. Sample MPS Input for LWC System

```
NAME          NITRO
ROWS
 N  OBJFCT
 E  RETURN1
 E  RETURN2
 E  RETURN3
 E  RETURN4
 E  RETURN5
 E  RETURN6
 E  RETURN7
 E  RETURN8
 E  RETURN9
 E  RETURN10
 L  CBU1
 L  CBU2
 L  CBU3
 L  CBU4
 L  CBU5
 L  CBU6
 L  CBU7
 L  CBU8
 L  CBU9
 L  CBU10
 L  WBU1
 L  WBU2
 L  WBU3
 L  WBU4
 L  WBU5
 L  WBU6
 L  WBU7
 L  WBU8
 L  WBU9
 L  WBU10
 L  SBU1
 L  SBU2
 L  SBU3
 L  SBU4
 L  SBU5
 L  SBU6
 L  SBU7
 L  SBU8
 L  SBU9
 L  SBU10
 L  BBU1
 L  BBU2
 L  BBU3
 L  BBU4
 L  BBU5
 L  BBU6
 L  BBU7
 L  BBU8
 L  BBU9
 L  BBU10
 L  LAND1
 L  LAND2
 L  LAND3
 L  LAND4
 L  LAND5
```

```
L   LAND6
L   LAND7
L   LAND8
L   LAND9
L   LAND10
L   CAP1
L   CAP2
L   CAP3
L   CAP4
L   CAP5
L   CAP6
L   CAP7
L   CAP8
L   CAP9
L   CAP10
L   APRL1
L   JUNL1
L   SEPTL1
L   OCTL1
L   APRL2
L   JUNL2
L   SEPTL2
L   OCTL2
L   APRL3
L   JUNL3
L   SEPTL3
L   OCTL3
L   APRL4
L   JUNL4
L   SEPTL4
L   OCTL4
L   APRL5
L   JUNL5
L   SEPTL5
L   OCTL5
L   APRL6
L   JUNL6
L   SEPTL6
L   OCTL6
L   APRL7
L   JUNL7
L   SEPTL7
L   OCTL7
L   APRL8
L   JUNL8
L   SEPTL8
L   OCTL8
L   APRL9
L   JUNL9
L   SEPTL9
L   OCTL9
L   APRL10
L   JUNL10
L   SEPTL10
L   OCTL10
E   OPL1
E   OPL2
E   OPL3
```

```
 E  OPL4
 E  OPL5
 E  OPL6
 E  OPL7
 E  OPL8
 E  OPL9
 E  OPL10
 L  MARL1
 L  MARL2
 L  MARL3
 L  MARL4
 L  MARL5
 L  MARL6
 L  MARL7
 L  MARL8
 L  MARL9
 L  MARL10
 E  SONLC1
 E  FINLC1
 E  CN1LC1
 E  CN2LC2
 E  CN3LC3
 L  NUPLC1
 E  RENLC1
 E  CLNLC1
 E  SONLC2
 E  FINLC2
 L  NUPLC2
 E  RENLC2
 E  CLNLC2
 E  SONLC3
 E  FINLC3
 L  NUPLC3
 E  RENLC3
 E  CLNLC3
 E  SONLC4
 E  FINLC4
 L  NUPLC4
 E  RENLC4
 E  CLNLC4
 E  SONLC5
 E  FINLC5
 L  NUPLC5
 E  RENLC5
 E  CLNLC5
 E  SONLC6
 E  FINLC6
 L  NUPLC6
 E  RENLC6
 E  CLNLC6
 E  SONLC7
 E  FINLC7
 L  NUPLC7
 E  RENLC7
 E  CLNLC7
 E  SONLC8
 E  FINLC8
 L  NUPLC8
```

```
 E  RENLC8
 E  CLNLC8
 E  SONLC9
 E  FINLC9
 L  NUPLC9
 E  RENLC9
 E  CLNLC9
 E  SONLC10
 E  FINLC10
 L  NUPLC10
 E  RENLC10
 E  CLNLC10
 E  IMNLC1
 E  IMNLC2
 E  IMNLC3
 E  IMNLC4
 E  IMNLC5
 E  IMNLC6
 E  IMNLC7
 E  IMNLC8
 E  IMNLC9
 E  IMNLC10
 E  NLLC1
 E  NLLC2
 E  NLLC3
 E  NLLC4
 E  NLLC5
 E  NLLC6
 E  NLLC7
 E  NLLC8
 E  NLLC9
 E  NLLC10
COLUMNS
    C1        RETURN1         2.20000   CBU1           1.00000
    C2        RETURN2         2.20000   CBU2           1.00000
    C3        RETURN3         2.20000   CBU3           1.00000
    C4        RETURN4         2.20000   CBU4           1.00000
    C5        RETURN5         2.20000   CBU5           1.00000
    C6        RETURN6         2.20000   CBU6           1.00000
    C7        RETURN7         2.20000   CBU7           1.00000
    C8        RETURN8         2.20000   CBU8           1.00000
    C9        RETURN9         2.20000   CBU9           1.00000
    C10       RETURN10        2.20000   CBU10          1.00000
    W1        RETURN1         2.73000   WBU1           1.00000
    W2        RETURN2         2.73000   WBU2           1.00000
    W3        RETURN3         2.73000   WBU3           1.00000
    W4        RETURN4         2.73000   WBU4           1.00000
    W5        RETURN5         2.73000   WBU5           1.00000
    W6        RETURN6         2.73000   WBU6           1.00000
    W7        RETURN7         2.73000   WBU7           1.00000
    W8        RETURN8         2.73000   WBU8           1.00000
    W9        RETURN9         2.73000   WBU9           1.00000
    W10       RETURN10        2.73000   WBU10          1.00000
    SB1       RETURN1         6.24000   SBU1           1.00000
    SB2       RETURN2         6.24000   SBU2           1.00000
    SB3       RETURN3         6.24000   SBU3           1.00000
    SB4       RETURN4         6.24000   SBU4           1.00000
    SB5       RETURN5         6.24000   SBU5           1.00000
```

```
SB6       RETURN6          6.24000   SBU6                1.00000
SB7       RETURN7          6.24000   SBU7                1.00000
SB8       RETURN8          6.24000   SBU8                1.00000
SB9       RETURN9          6.24000   SBU9                1.00000
SB10      RETURN10         6.24000   SBU10               1.00000
B1        RETURN1          1.94000   BBU1                1.00000
B2        RETURN2          1.94000   BBU2                1.00000
B3        RETURN3          1.94000   BBU3                1.00000
B4        RETURN4          1.94000   BBU4                1.00000
B5        RETURN5          1.94000   BBU5                1.00000
B6        RETURN6          1.94000   BBU6                1.00000
B7        RETURN7          1.94000   BBU7                1.00000
B8        RETURN8          1.94000   BBU8                1.00000
B9        RETURN9          1.94000   BBU9                1.00000
B10       RETURN10         1.94000   BBU10               1.00000
LAPR1     RETURN1    -     4.00000   CAP1                4.00000
LAPR1     APRL1      -     1.00000   OPL1        -       1.00000
LJUN1     RETURN1    -     4.00000   CAP1                4.00000
LJUN1     JUNL1      -     1.00000   OPL1        -       1.00000
LSEP1     RETURN1    -     4.00000   CAP1                4.00000
LSEP1     SEPTL1     -     1.00000   OPL1        -       1.00000
LOCT1     RETURN1    -     4.00000   CAP1                4.00000
LOCT1     OCTL1      -     1.00000   OPL1        -       1.00000
LAPR2     RETURN2    -     4.00000   CAP2                4.00000
LAPR2     APRL2      -     1.00000   OPL2        -       1.00000
LJUN2     RETURN2    -     4.00000   CAP2                4.00000
LJUN2     JUNL2      -     1.00000   OPL2        -       1.00000
LSEP2     RETURN2    -     4.00000   CAP2                4.00000
LSEP2     SEPTL2     -     1.00000   OPL2        -       1.00000
LOCT2     RETURN2    -     4.00000   CAP2                4.00000
LOCT2     OCTL2      -     1.00000   OPL2        -       1.00000
LAPR3     RETURN3    -     4.00000   CAP3                4.00000
LAPR3     APRL3      -     1.00000   OPL3        -       1.00000
LJUN3     RETURN3    -     4.00000   CAP3                4.00000
LJUN3     JUNL3      -     1.00000   OPL3        -       1.00000
LSEP3     RETURN3    -     4.00000   CAP3                4.00000
LSEP3     SEPTL3     -     1.00000   OPL3        -       1.00000
LOCT3     RETURN3    -     4.00000   CAP3                4.00000
LOCT3     OCTL3      -     1.00000   OPL3        -       1.00000
LAPR4     RETURN4    -     4.00000   CAP4                4.00000
LAPR4     APRL4      -     1.00000   OPL4        -       1.00000
LJUN4     RETURN4    -     4.00000   CAP4                4.00000
LJUN4     JUNL4      -     1.00000   OPL4        -       1.00000
LSEP4     RETURN4    -     4.00000   CAP4                4.00000
LSEP4     SEPTL4     -     1.00000   OPL4        -       1.00000
LOCT4     RETURN4    -     4.00000   CAP4                4.00000
LOCT4     OCTL4      -     1.00000   OPL4        -       1.00000
LAPR5     RETURN5    -     4.00000   CAP5                4.00000
LAPR5     APRL5      -     1.00000   OPL5        -       1.00000
LJUN5     RETURN5    -     4.00000   CAP5                4.00000
LJUN5     JUNL5      -     1.00000   OPL5        -       1.00000
LSEP5     RETURN5    -     4.00000   CAP5                4.00000
LSEP5     SEPTL5     -     1.00000   OPL5        -       1.00000
LOCT5     RETURN5    -     4.00000   CAP5                4.00000
LOCT5     OCTL5      -     1.00000   OPL5        -       1.00000
LAPR6     RETURN6    -     4.00000   CAP6                4.00000
LAPR6     APRL6      -     1.00000   OPL6        -       1.00000
LJUN6     RETURN6    -     4.00000   CAP6                4.00000
```

```
LJUN6     JUNL6     -   1.00000   OPL6      -    1.00000
LSEP6     RETURN6   -   4.00000   CAP6           4.00000
LSEP6     SEPTL6    -   1.00000   OPL6      -    1.00000
LOCT6     RETURN6   -   4.00000   CAP6           4.00000
LOCT6     OCTL6     -   1.00000   OPL6      -    1.00000
LAPR7     RETURN7   -   4.00000   CAP7           4.00000
LAPR7     APRL7     -   1.00000   OPL7      -    1.00000
LJUN7     RETURN7   -   4.00000   CAP7           4.00000
LJUN7     JUNL7     -   1.00000   OPL7      -    1.00000
LSEP7     RETURN7   -   4.00000   CAP7           4.00000
LSEP7     SEPTL7    -   1.00000   OPL7      -    1.00000
LOCT7     RETURN7   -   4.00000   CAP7           4.00000
LOCT7     OCTL7     -   1.00000   OPL7      -    1.00000
LAPR8     RETURN8   -   4.00000   CAP8           4.00000
LAPR8     APRL8     -   1.00000   OPL8      -    1.00000
LJUN8     RETURN8   -   4.00000   CAP8           4.00000
LJUN8     JUNL8     -   1.00000   OPL8      -    1.00000
LSEP8     RETURN8   -   4.00000   CAP8           4.00000
LSEP8     SEPTL8    -   1.00000   OPL8      -    1.00000
LOCT8     RETURN8   -   4.00000   CAP8           4.00000
LOCT8     OCTL8     -   1.00000   OPL8      -    1.00000
LAPR9     RETURN9   -   4.00000   CAP9           4.00000
LAPR9     APRL9     -   1.00000   OPL9      -    1.00000
LJUN9     RETURN9   -   4.00000   CAP9           4.00000
LJUN9     JUNL9     -   1.00000   OPL9      -    1.00000
LSEP9     RETURN9   -   4.00000   CAP9           4.00000
LSEP9     SEPTL9    -   1.00000   OPL9      -    1.00000
LOCT9     RETURN9   -   4.00000   CAP9           4.00000
LOCT9     OCTL9     -   1.00000   OPL9      -    1.00000
LAPR10    RETURN10  -   4.00000   CAP10          4.00000
LAPR10    APRL10    -   1.00000   OPL10     -    1.00000
LJUN10    RETURN10  -   4.00000   CAP10          4.00000
LJUN10    JUNL10    -   1.00000   OPL10     -    1.00000
LSEP10    RETURN10  -   4.00000   CAP10          4.00000
LSEP10    SEPTL10   -   1.00000   OPL10     -    1.00000
LOCT10    RETURN10  -   4.00000   CAP10          4.00000
LOCT10    OCTL10    -   1.00000   OPL10     -    1.00000
LOP1      OPL1      -   1.00000
LOP2      OPL2      -   1.00000
LOP3      OPL3      -   1.00000
LOP4      OPL4      -   1.00000
LOP5      OPL5      -   1.00000
LOP6      OPL6      -   1.00000
LOP7      OPL7      -   1.00000
LOP8      OPL8      -   1.00000
LOP9      OPL9      -   1.00000
LOP10     OPL10     -   1.00000
INT1      RETURN1   -    .10500   CAP1      -    1.00000
INT2      RETURN2   -    .10500   CAP2      -    1.00000
INT3      RETURN3   -    .10500   CAP3      -    1.00000
INT4      RETURN4   -    .10500   CAP4      -    1.00000
INT5      RETURN5   -    .10500   CAP5      -    1.00000
INT6      RETURN6   -    .10500   CAP6      -    1.00000
INT7      RETURN7   -    .10500   CAP7      -    1.00000
INT8      RETURN8   -    .10500   CAP8      -    1.00000
INT9      RETURN9   -    .10500   CAP9      -    1.00000
INT10     RETURN10  -    .10500   CAP10     -    1.00000
RET1      OBJFCT        1.00000   RETURN1   -    1.00000
```

```
RET2      OBJFCT            .95240  RETURN2    -    1.00000
RET3      OBJFCT            .90700  RETURN3    -    1.00000
RET4      OBJFCT            .86380  RETURN4    -    1.00000
RET5      OBJFCT            .82270  RETURN5    -    1.00000
RET6      OBJFCT            .78350  RETURN6    -    1.00000
RET7      OBJFCT            .74620  RETURN7    -    1.00000
RET8      OBJFCT            .71070  RETURN8    -    1.00000
RET9      OBJFCT            .67680  RETURN9    -    1.00000
RET10     OBJFCT            .64460  RETURN10   -    1.00000
LC1       RETURN1    -   145.58000  CBU1       -   50.00000
LC1       WBU1       -    11.00000  BBU1       -   13.50000
LC1       SBU1       -    11.66000  LAND1           1.00000
LC1       CAP1           145.58000  MARL1            .11400
LC1       APRL1             .60560  JUNL1            .39790
LC1       SEPTL1            .85840  OCTL1            .64740
LC1       OPL1             2.62330  SONLC1         30.00000
LC1       FINLC1          47.70000  CN1LC1         15.60000
LC1       NUPLC1         168.60000  RENLC1         54.40000
LC1       CLNLC1          50.00000
LC2       RETURN2    -   145.58000  CBU2       -   50.00000
LC2       WBU2       -    11.00000  BBU2       -   13.50000
LC2       SBU2       -    11.66000  LAND2           1.00000
LC2       CAP2           145.58000  MARL2            .11400
LC2       APRL2             .60560  JUNL2            .39790
LC2       SEPTL2            .85840  OCTL2            .64740
LC2       OPL2             2.62330  SONLC2         30.00000
LC2       FINLC2          47.70000  NUPLC2        168.60000
LC2       RENLC2          54.40000  CLNLC2         50.00000
LC2       CN2LC2           4.50000
LC3       RETURN3    -   145.58000  CBU3       -   50.00000
LC3       WBU3       -    11.00000  BBU3       -   13.50000
LC3       SBU3       -    11.66000  LAND3           1.00000
LC3       CAP3           145.58000  MARL3            .11400
LC3       APRL3             .60560  JUNL3            .39790
LC3       SEPTL3            .85840  OCTL3            .64740
LC3       OPL3             2.62330  SONLC3         30.00000
LC3       FINLC3          47.70000  NUPLC3        168.60000
LC3       RENLC3          54.40000  CLNLC3         50.00000
LC3       CN3LC3           1.70000
LC4       RETURN4    -   145.58000  CBU4       -   50.00000
LC4       WBU4       -    11.00000  BBU4       -   13.50000
LC4       SBU4       -    11.66000  LAND4           1.00000
LC4       CAP4           145.58000  MARL4            .11400
LC4       APRL4             .60560  JUNL4            .39790
LC4       SEPTL4            .85840  OCTL4            .64740
LC4       OPL4             2.62330  SONLC4         30.00000
LC4       FINLC4          47.70000  NUPLC4        168.60000
LC4       RENLC4          54.40000  CLNLC4         50.00000
LC5       RETURN5    -   145.58000  CBU5       -   50.00000
LC5       WBU5       -    11.00000  BBU5       -   13.50000
LC5       SBU5       -    11.66000  LAND5           1.00000
LC5       CAP5           145.58000  MARL5            .11400
LC5       APRL5             .60560  JUNL5            .39790
LC5       SEPTL5            .85840  OCTL5            .64740
LC5       OPL5             2.62330  SONLC5         30.00000
LC5       FINLC5          47.70000  NUPLC5        168.60000
LC5       RENLC5          54.40000  CLNLC5         50.00000
LC6       RETURN6    -   145.58000  CBU6       -   50.00000
```

```
LC6       WBU6       -   11.00000   BBU6       -   13.50000
LC6       SBU6       -   11.66000   LAND6           1.00000
LC6       CAP6          145.58000   MARL6            .11400
LC6       APRL6            .60560   JUNL6            .39790
LC6       SEPTL6           .85840   OCTL6            .64740
LC6       OPL6            2.62330   SONLC6         30.00000
LC6       FINLC6         47.70000   NUPLC6        168.60000
LC6       RENLC6         54.40000   CLNLC6         50.00000
LC7       RETURN7    -  145.58000   CBU7       -   50.00000
LC7       WBU7       -   11.00000   BBU7       -   13.50000
LC7       SBU7       -   11.66000   LAND7           1.00000
LC7       CAP7          145.58000   MARL7            .11400
LC7       APRL7            .60560   JUNL7            .39790
LC7       SEPTL7           .85840   OCTL7            .64740
LC7       OPL7            2.62330   SONLC7         30.00000
LC7       FINLC7         47.70000   NUPLC7        168.60000
LC7       RENLC7         54.40000   CLNLC7         50.00000
LC8       RETURN8    -  145.58000   CBU8       -   50.00000
LC8       WBU8       -   11.00000   BBU8       -   13.50000
LC8       SBU8       -   11.66000   LAND8           1.00000
LC8       CAP8          145.58000   MARL8            .11400
LC8       APRL8            .60560   JUNL8            .39790
LC8       SEPTL8           .85840   OCTL8            .64740
LC8       OPL8            2.62330   SONLC8         30.00000
LC8       FINLC8         47.70000   NUPLC8        168.60000
LC8       RENLC8         54.40000   CLNLC8         50.00000
LC9       RETURN9    -  145.58000   CBU9       -   50.00000
LC9       WBU9       -   11.00000   BBU9       -   13.50000
LC9       SBU9       -   11.66000   LAND9           1.00000
LC9       CAP9          145.58000   MARL9            .11400
LC9       APRL9            .60560   JUNL9            .39790
LC9       SEPTL9           .85840   OCTL9            .64740
LC9       OPL9            2.62330   SONLC9         30.00000
LC9       FINLC9         47.70000   NUPLC9        168.60000
LC9       RENLC9         54.40000   CLNLC9         50.00000
LC10      RETURN10   -  145.58000   CBU10      -   50.00000
LC10      WBU10      -   11.00000   BBU10      -   13.50000
LC10      SBU10      -   11.66000   LAND10          1.00000
LC10      CAP10         145.58000   MARL10           .11400
LC10      APRL10           .60560   JUNL10           .39790
LC10      SEPTL10          .85840   OCTL10           .64740
LC10      OPL10           2.62330   SONLC10        30.00000
LC10      FINLC10        47.70000   NUPLC10       168.60000
LC10      RENLC10        54.40000   CLNLC10        50.00000
LMAR1     RETURN1    -    4.00000   CAP1            4.00000
LMAR1     MARL1      -    1.00000   OPL1       -    1.00000
LMAR2     RETURN2    -    4.00000   CAP2            4.00000
LMAR2     MARL2      -    1.00000   OPL2       -    1.00000
LMAR3     RETURN3    -    4.00000   CAP3            4.00000
LMAR3     MARL3      -    1.00000   OPL3       -    1.00000
LMAR4     RETURN4    -    4.00000   CAP4            4.00000
LMAR4     MARL4      -    1.00000   OPL4       -    1.00000
LMAR5     RETURN5    -    4.00000   CAP5            4.00000
LMAR5     MARL5      -    1.00000   OPL5       -    1.00000
LMAR6     RETURN6    -    4.00000   CAP6            4.00000
LMAR6     MARL6      -    1.00000   OPL6       -    1.00000
LMAR7     RETURN7    -    4.00000   CAP7            4.00000
LMAR7     MARL7      -    1.00000   OPL7       -    1.00000
```

```
LMAR8     RETURN8   -    4.00000   CAP8            4.00000
LMAR8     MARL8     -    1.00000   OPL8       -    1.00000
LMAR9     RETURN9   -    4.00000   CAP9            4.00000
LMAR9     MARL9     -    1.00000   OPL9       -    1.00000
LMAR10    RETURN10  -    4.00000   CAP10           4.00000
LMAR10    MARL10    -    1.00000   OPL10      -    1.00000
SNLC1     SONLC1    -    1.00000   NUPLC1     -    1.00000
FNLC1     FINLC1    -    1.00000   NUPLC1     -    1.00000
CONLC1    CN1LC1    -    1.00000   NUPLC1     -    1.00000
PNLC1     RETURN1   -     .27000   CAP1             .27000
PNLC1     NUPLC1    -     .60000   IMNLC1           .02000
PNLC1     NLLC1           .13000
RNLC1     RENLC1    -    1.00000   NUPLC2     -     .15000
RNLC1     NUPLC3    -     .05000   NUPLC4     -     .03000
RNLC1     NLLC1           .62000
LNLC1     CLNLC1    -    1.00000   NUPLC2     -     .60000
LNLC1     NUPLC3    -     .10000   NUPLC4     -     .10000
LNLC1     NUPLC5    -     .05000
TNLC1-2   IMNLC1    -    1.00000   NUPLC2     -    1.00000
SNLC2     SONLC2    -    1.00000   NUPLC2     -    1.00000
FNLC2     FINLC2    -    1.00000   NUPLC2     -    1.00000
CONLC2    CN2LC2    -    1.00000   NUPLC2     -    1.00000
PNLC2     RETURN2   -     .27000   CAP2             .27000
PNLC2     NUPLC2    -     .60000   IMNLC2           .02000
PNLC2     NLLC2           .13000
RNLC2     RENLC2    -    1.00000   NUPLC3     -     .15000
RNLC2     NUPLC4    -     .05000   NUPLC5     -     .03000
RNLC2     NLLC2           .62000
LNLC2     CLNLC2    -    1.00000   NUPLC3     -     .60000
LNLC2     NUPLC4    -     .10000   NUPLC5     -     .10000
LNLC2     NUPLC6    -     .05000
TNLC2-3   IMNLC2    -    1.00000   NUPLC3     -    1.00000
SNLC3     SONLC3    -    1.00000   NUPLC3     -    1.00000
FNLC3     FINLC3    -    1.00000   NUPLC3     -    1.00000
CONLC3    CN3LC3    -    1.00000   NUPLC3     -    1.00000
PNLC3     RETURN3   -     .27000   CAP3             .27000
PNLC3     NUPLC3    -     .60000   IMNLC3           .02000
PNLC3     NLLC3           .13000
RNLC3     RENLC3    -    1.00000   NUPLC4     -     .15000
RNLC3     NUPLC5    -     .05000   NUPLC6     -     .03000
RNLC3     NLLC3           .62000
LNLC3     CLNLC3    -    1.00000   NUPLC4     -     .60000
LNLC3     NUPLC5    -     .10000   NUPLC6     -     .10000
LNLC3     NUPLC7    -     .05000
TNLC3-4   IMNLC3    -    1.00000   NUPLC4     -    1.00000
SNLC4     SONLC4    -    1.00000   NUPLC4     -    1.00000
FNLC4     FINLC4    -    1.00000   NUPLC4     -    1.00000
PNLC4     RETURN4   -     .27000   CAP4             .27000
PNLC4     NUPLC4    -     .60000   IMNLC4           .02000
PNLC4     NLLC4           .13000
RNLC4     RENLC4    -    1.00000   NUPLC5     -     .15000
RNLC4     NUPLC6    -     .05000   NUPLC7     -     .03000
RNLC4     NLLC4           .62000
LNLC4     CLNLC4    -    1.00000   NUPLC5     -     .60000
LNLC4     NUPLC6    -     .10000   NUPLC7     -     .10000
LNLC4     NUPLC8    -     .05000
TNLC4-5   IMNLC4    -    1.00000   NUPLC5     -    1.00000
SNLC5     SONLC5    -    1.00000   NUPLC5     -    1.00000
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FNLC5     FINLC5    -    1.00000   NUPLC5    -    1.00000
PNLC5     RETURN5   -     .27000   CAP5            .27000
PNLC5     NUPLC5    -     .60000   IMNLC5          .02000
PNLC5     NLLC5           .13000
RNLC5     RENLC5    -    1.00000   NUPLC6    -     .15000
RNLC5     NUPLC7    -     .05000   NUPLC8    -     .03000
RNLC5     NLLC5           .62000
LNLC5     CLNLC5    -    1.00000   NUPLC6    -     .60000
LNLC5     NUPLC7    -     .10000   NUPLC8    -     .10000
LNLC5     NUPLC9    -     .05000
TNLC5-6   IMNLC5    -    1.00000   NUPLC6    -    1.00000
SNLC6     SONLC6    -    1.00000   NUPLC6    -    1.00000
FNLC6     FINLC6    -    1.00000   NUPLC6    -    1.00000
PNLC6     RETURN6   -     .27000   CAP6            .27000
PNLC6     NUPLC6    -     .60000   IMNLC6          .02000
PNLC6     NLLC6           .13000
RNLC6     RENLC6    -    1.00000   NUPLC7    -     .15000
RNLC6     NUPLC8    -     .05000   NUPLC9    -     .03000
RNLC6     NLLC6           .62000
LNLC6     CLNLC6    -    1.00000   NUPLC7    -     .60000
LNLC6     NUPLC8    -     .10000   NUPLC9    -     .10000
LNLC6     NUPLC10   -     .05000
TNLC6-7   IMNLC6    -    1.00000   NUPLC7    -    1.00000
SNLC7     SONLC7    -    1.00000   NUPLC7    -    1.00000
FNLC7     FINLC7    -    1.00000   NUPLC7    -    1.00000
PNLC7     RETURN7   -     .27000   CAP7            .27000
PNLC7     NUPLC7    -     .60000   IMNLC7          .02000
PNLC7     NLLC7           .13000
RNLC7     RENLC7    -    1.00000   NUPLC8    -     .15000
RNLC7     NUPLC9    -     .05000   NUPLC10   -     .03000
RNLC7     NLLC7           .62000
LNLC7     CLNLC7    -    1.00000   NUPLC8    -     .60000
LNLC7     NUPLC9    -     .10000   NUPLC10   -     .10000
TNLC7-8   IMNLC7    -    1.00000   NUPLC8    -    1.00000
SNLC8     SONLC8    -    1.00000   NUPLC8    -    1.00000
FNLC8     FINLC8    -    1.00000   NUPLC8    -    1.00000
PNLC8     RETURN8   -     .27000   CAP8            .27000
PNLC8     NUPLC8    -     .60000   IMNLC8          .02000
PNLC8     NLLC8           .13000
RNLC8     RENLC8    -    1.00000   NUPLC9    -     .15000
RNLC8     NUPLC10   -     .05000   NLLC8           .62000
LNLC8     CLNLC8    -    1.00000   NUPLC9    -     .60000
LNLC8     NUPLC10   -     .10000
TNLC8-9   IMNLC8    -    1.00000   NUPLC9    -    1.00000
SNLC9     SONLC9    -    1.00000   NUPLC9    -    1.00000
FNLC9     FINLC9    -    1.00000   NUPLC9    -    1.00000
PNLC9     RETURN9   -     .27000   CAP9            .27000
PNLC9     NUPLC9    -     .60000   IMNLC9          .02000
PNLC9     NLLC9           .13000
RNLC9     RENLC9    -    1.00000   NUPLC10   -     .15000
RNLC9     NLLC9           .62000
LNLC9     CLNLC9    -    1.00000   NUPLC10   -     .60000
TNLC9-10  IMNLC9    -    1.00000   NUPLC10   -    1.00000
SNLC10    SONLC10   -    1.00000   NUPLC10   -    1.00000
FNLC10    FINLC10   -    1.00000   NUPLC10   -    1.00000
PNLC10    RETURN10  -     .27000   CAP10           .27000
PNLC10    NUPLC10   -     .60000   IMNLC10         .02000
PNLC10    NLLC10          .13000
```

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    RNLC10    RENLC10   -    1.00000   NLLC10          .62000
    LNLC10    CLNLC10   -    1.00000
    TLC10-11  IMNLC10   -    1.00000
    RLC1      NLLC1     -    1.00000
    RLC2      NLLC2     -    1.00000
    RLC3      NLLC3     -    1.00000
    RLC4      NLLC4     -    1.00000
    RLC5      NLLC5     -    1.00000
    RLC6      NLLC6     -    1.00000
    RLC7      NLLC7     -    1.00000
    RLC8      NLLC8     -    1.00000
    RLC9      NLLC9     -    1.00000
    RLC10     NLLC10    -    1.00000
RHS
    RHS       LAND1        500.00000   LAND2        500.00000
    RHS       LAND3        500.00000   LAND4        500.00000
    RHS       LAND5        500.00000   LAND6        500.00000
    RHS       LAND7        500.00000   LAND8        500.00000
    RHS       LAND9        500.00000   LAND10       500.00000
    RHS       APRL1        153.00000   JUNL1        249.00000
    RHS       SEPTL1       287.00000   OCTL1        185.00000
    RHS       APRL2        153.00000   JUNL2        249.00000
    RHS       SEPTL2       287.00000   OCTL2        185.00000
    RHS       APRL3        153.00000   JUNL3        249.00000
    RHS       SEPTL3       287.00000   OCTL3        185.00000
    RHS       APRL4        153.00000   JUNL4        249.00000
    RHS       SEPTL4       287.00000   OCTL4        185.00000
    RHS       APRL5        153.00000   JUNL5        249.00000
    RHS       SEPTL5       287.00000   OCTL5        185.00000
    RHS       APRL6        153.00000   JUNL6        249.00000
    RHS       SEPTL6       287.00000   OCTL6        185.00000
    RHS       APRL7        153.00000   JUNL7        249.00000
    RHS       SEPTL7       287.00000   OCTL7        185.00000
    RHS       APRL8        153.00000   JUNL8        249.00000
    RHS       SEPTL8       287.00000   OCTL8        185.00000
    RHS       APRL9        153.00000   JUNL9        249.00000
    RHS       SEPTL9       287.00000   OCTL9        185.00000
    RHS       APRL10       153.00000   JUNL10       249.00000
    RHS       SEPTL10      287.00000   OCTL10       185.00000
    RHS       MARL1        153.00000   MARL2        153.00000
    RHS       MARL3        153.00000   MARL4        153.00000
    RHS       MARL5        153.00000   MARL6        153.00000
    RHS       MARL7        153.00000   MARL8        153.00000
    RHS       MARL9        153.00000   MARL10       153.00000
ENDATA
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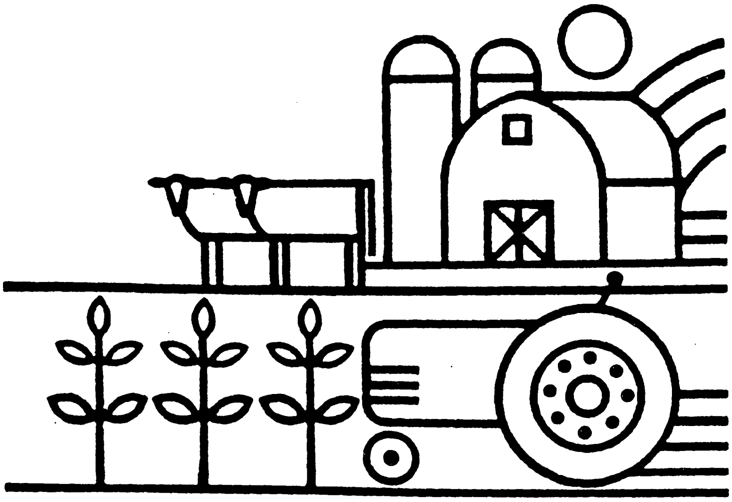
# Appendix D. Farmer Survey and Letters to Farmers

# Alternative Nitrogen Sources in Agriculture
## A Survey for Virginia Farmers



*Department of Agricultural Economics*
*Virginia Polytechnic Institute and State University*
*Blacksburg, Virginia 24061*

Many people say that farming is changing in response to financial pressures and increasing off-farm job opportunities. Please answer these questions about your farm operation and how it has changed over the past five years.

1. Size of your farm in 1988:

    _____ ACRES OWNED

    _____ ACRES RENTED

2. Size of your farm five years ago:

    _____ ACRES OWNED

    _____ ACRES RENTED

3. How many acres of the following crops will you plant in 1988? (If you do not plan to grow crops, skip to question 5.)

    CORN _____ acres

    WHEAT _____ acres

    BARLEY _____ acres

    SOYBEANS

    double-crop _____ acres

    full season _____ acres

    ALFALFA _____ acres

    PASTURE _____ acres

    OTHER (list):

    _____________ _____ acres

    _____________ _____ acres

4. An example of a common crop rotation over a five year period for a grain farmer is:

    YEAR 1 Corn

    YEAR 2 Small grain/soybeans double-cropped

    YEAR 3 Corn

    YEAR 4 Small grain/soybeans double-cropped

    YEAR 5 Corn

    Describe the crop rotation you plan to follow for the next five years.

    1988 ______________________________

    1989 ______________________________

    1990 ______________________________

    1991 ______________________________

    1992 ______________________________

5. What crops were you growing five years ago? (If you were not growing crops or farming five years ago, go to question 6.)

| | | |
|---|---|---|
| CORN | YES | NO |
| WHEAT | YES | NO |
| BARLEY | YES | NO |
| SOYBEANS | | |
| double-crop | YES | NO |
| full season | YES | NO |
| ALFALFA | YES | NO |
| PASTURE | YES | NO |
| OTHER (list): | | |
| ________________ | YES | NO |
| ________________ | YES | NO |

6. Do you currently have livestock on your farm?

_____ NO (skip to question 7)
_____ YES (please list below)

| | | |
|---|---|---|
| Dairy cattle | _____ | head |
| Beef cattle | _____ | head |
| Swine | _____ | head |
| Sheep | _____ | head |
| Poultry | _____ | birds |

7. Did you have livestock on your farm five years ago? Ten years ago?

| | 5 years ago | | 10 years ago | |
|---|---|---|---|---|
| Dairy cattle | YES | NO | YES | NO |
| Beef cattle | YES | NO | YES | NO |
| Swine | YES | NO | YES | NO |
| Sheep | YES | NO | YES | NO |
| Poultry | YES | NO | YES | NO |

For the rest of this survey, we ask questions which apply specifically to producers of row crops. If you do not grow row crops, please stop here and return this survey in the enclosed pre-paid envelope. Thank you for your help.

8. Some farmers have expressed concern about the profitability and environmental effects of their crop production systems. We would like to know what you think about their concerns. Please indicate how strongly you agree or disagree with each of the following statements <u>for your farm operation</u>.

| | STRONGLY AGREE | | | STRONGLY DISAGREE |
|---|---|---|---|---|
| I should increase the number of crops I plant in order to be less dependent on just a few crops. | 4 | 3 | 2 | 1 |
| My current rotation and fertilizer practices are reducing the productivity of the soil. | 4 | 3 | 2 | 1 |
| Insect problems seem to be increasing with my current production system. | 4 | 3 | 2 | 1 |
| Weed problems seem to be increasing with my current production system. | 4 | 3 | 2 | 1 |
| My current production system depends too much on fuel, fertilizers, and pesticides which may become scarce or too expensive. | 4 | 3 | 2 | 1 |
| Maximizing yields is not as important as minimizing my production expenses. | 4 | 3 | 2 | 1 |
| The loss of chemicals from cropland is an important cause of water pollution. | 4 | 3 | 2 | 1 |
| Pesticides used on the farm may pose health risks for humans and animals. | 4 | 3 | 2 | 1 |
| I am not able to devote more time to managing my farm operation. | 4 | 3 | 2 | 1 |

9. Nitrogen can be a significant production expense. How many pounds of purchased nitrogen will you apply per acre for the crops you plant in 1988? (If you apply a mixed fertilizer and do not know exactly how much nitrogen you apply, please list both total pounds of fertilizer and the mixture you use, for example 100 pounds of 10-10-10.)

| | GRANULAR FORM | LIQUID FORM |
|---|---|---|
| CORN | _____ lbs/acre | _____ lbs/acre |
| WHEAT | _____ lbs/acre | _____ lbs/acre |
| BARLEY | _____ lbs/acre | _____ lbs/acre |
| PASTURE | _____ lbs/acre | _____ lbs/acre |
| OTHER (list): | | |
| _______________ | _____ lbs/acre | _____ lbs/acre |
| _______________ | _____ lbs/acre | _____ lbs/acre |

10. Consider the total nitrogen which you will apply to all crops in 1988. Has that amount increased or decreased over the last five years? (check one)

_____ TOTAL NITROGEN APPLIED HAS INCREASED.
_____ TOTAL NITROGEN APPLIED HAS DECREASED.
_____ TOTAL NITROGEN APPLIED HAS NOT CHANGED.

11. How do you decide how much nitrogen fertilizer to apply?

_____ EXPERIENCE
_____ EXTENSION RECOMMENDATIONS
_____ VIRGINIA TECH SOIL TEST
_____ COMMERCIAL SOIL TEST
_____ FERTILIZER DEALER RECOMMENDATIONS
_____ OTHER (list): _________________________

For the next group of questions, we will first describe an approach which might be used to provide nitrogen for crops. Read each description and think about how the nitrogen application system compares to your current fertilization program. Then, for each system, respond to the questions which follow.

Approach #1. In a corn, wheat, soybean rotation, nitrogen fertilizer is applied to corn in two separate applications. 25 lbs/acre of nitrogen is applied at planting. Then 110 lbs/acre is applied 25-30 days after the corn emerges.

12. Do you currently use two separate applications of nitrogen for corn?

_____ YES

_____ NO

13. What do you think about the practice of splitting nitrogen fertilizer into two separate applications?

| | STRONGLY AGREE | | | STRONGLY DISAGREE |
|---|---|---|---|---|
| 135 pounds of nitrogen per acre is enough for a 100 bushel corn yield. | 4 | 3 | 2 | 1 |
| Splitting nitrogen into two separate applications is too costly and time consuming. | 4 | 3 | 2 | 1 |
| Splitting nitrogen applications reduces the total amount of nitrogen fertilizer required. | 4 | 3 | 2 | 1 |
| Splitting nitrogen applications reduces the amount of nitrogen that will be lost from the field during a rain storm. | 4 | 3 | 2 | 1 |

14. Would the following encourage you to split applications of nitrogen for corn instead of applying all nitrogen at planting? (If you already use split applications, go to Approach #2 and question 15.)

| | WOULD STRONGLY ENCOURAGE ME | | | WOULD NOT ENCOURAGE ME |
|---|---|---|---|---|
| Reliable information on the stage of growth when plants need the most nitrogen. | 4 | 3 | 2 | 1 |
| Evidence that total nitrogen applied can be reduced with split applications. | 4 | 3 | 2 | 1 |
| Cash payment of $25.00 for each acre fertilized with split applications. | 4 | 3 | 2 | 1 |
| A 10 cent per pound increase in the price of nitrogen fertilizer. | 4 | 3 | 2 | 1 |

Approach #2. In a corn, wheat, soybean rotation, a nitrogen-fixing legume is overseeded into soybeans before the soybeans are harvested. In the spring, the legume is disked under and corn is planted.

15. Do you currently use a legume as a green manure to provide nitrogen for corn?

_____ YES

_____ NO

16. What do you think about using a legume to provide nitrogen for corn?

| | STRONGLY AGREE | | | STRONGLY DISAGREE |
|---|---|---|---|---|
| The legume can supply most of the nitrogen for the corn crop. | 4 | 3 | 2 | 1 |
| Some of the nitrogen from the legume would still be left for the wheat crop. | 4 | 3 | 2 | 1 |
| Nitrogen from legumes is less likely than fertilizer nitrogen to be lost from the field during a rain storm. | 4 | 3 | 2 | 1 |
| Legumes will improve a soil's physical properties. | 4 | 3 | 2 | 1 |
| Using legume cover crops is too costly and time consuming. | 4 | 3 | 2 | 1 |

17. Would the following encourage you to use a nitrogen-fixing legume as a green manure to supply part or all of the nitrogen for corn? (If you already use a legume green manure, go to Approach #3 and question 18.)

| | WOULD STRONGLY ENCOURAGE ME | | | WOULD NOT ENCOURAGE ME |
|---|---|---|---|---|
| Evidence that long term soil fertility can be enhanced by legumes. | 4 | 3 | 2 | 1 |
| Availability of free tissue analysis service to determine nitrogen content of legumes. | 4 | 3 | 2 | 1 |
| Cash payment of $25.00 for each acre planted with a legume for green manure. | 4 | 3 | 2 | 1 |
| A 10 cent per pound increase in the price of nitrogen fertilizer. | 4 | 3 | 2 | 1 |

Approach #3. In a corn, wheat, soybean rotation, livestock manure is used to provide part or all of the nitrogen required by the corn. (Please respond to these questions even if you do not have livestock.)

18. Do you use livestock manure to provide nitrogen for corn?

_____ YES

_____ NO

19. What do you think about using animal manure to provide nitrogen for corn?

| | STRONGLY AGREE | | | STRONGLY DISAGREE |
|---|---|---|---|---|
| The nitrogen content of the manure will decrease if the manure is not disked into the soil. | 4 | 3 | 2 | 1 |
| Manure can supply most of the nitrogen for the corn crop. | 4 | 3 | 2 | 1 |
| Some of the nitrogen from the manure will still be left for the wheat crop. | 4 | 3 | 2 | 1 |
| Nitrogen from manure is less likely than fertilizer nitrogen to be lost from the field during a rain storm. | 4 | 3 | 2 | 1 |
| Manure will improve a soil's physical properties. | 4 | 3 | 2 | 1 |
| Livestock and livestock manure use are too costly and time consuming. | 4 | 3 | 2 | 1 |

20. Would the following encourage you to use livestock manure to supply part or all of corn nitrogen requirements? (If you already use livestock manure for nitrogen, go to Approach #4 and question 21.)

| | WOULD STRONGLY ENCOURAGE ME | | WOULD NOT ENCOURAGE ME | |
|---|---|---|---|---|
| Evidence that long term soil fertility can be enhanced by manures. | 4 | 3 | 2 | 1 |
| Availability of free manure testing service to determine nitrogen content of manures. | 4 | 3 | 2 | 1 |
| Cash payment of $25.00 for each acre on which 2 tons of manure is applied and nitrogen fertilizer is reduced by 25 pounds. | 4 | 3 | 2 | 1 |
| A 10 cent per pound increase in the price of nitrogen fertilizer. | 4 | 3 | 2 | 1 |

Approach #4. In a corn, wheat, soybean rotation, composted poultry litter is used to provide part or all of the nitrogen required by the corn. The litter is delivered and spread by a dealer just like nitrogen fertilizer. (Please respond to these questions even if poultry litter is not available in your area.)

21. Do you currently use composted poultry litter to provide nitrogen for corn?

_____ YES

_____ NO

22. What do you think about using composted poultry litter to provide nitrogen for corn?

| | STRONGLY AGREE | | | STRONGLY DISAGREE |
|---|---|---|---|---|
| Poultry litter can supply most of the nitrogen for the corn crop. | 4 | 3 | 2 | 1 |
| Some of the nitrogen from poultry litter will still be left for the wheat crop. | 4 | 3 | 2 | 1 |
| Composted poultry litter has an odor which would offend me and my neighbors. | 4 | 3 | 2 | 1 |
| Nitrogen in poultry litter is less likely than fertilizer nitrogen to be lost from the field during a rain storm. | 4 | 3 | 2 | 1 |
| Poultry litter will improve a soi's physical properties. | 4 | 3 | 2 | 1 |

23. Which of the following would encourage you to use composted poultry litter to supply part or all of corn nitrogen requirements? (If you already use poultry litter for nitrogen, go to question 24.)

| | WOULD STRONGLY ENCOURAGE ME | | | WOULD NOT ENCOURAGE ME |
|---|---|---|---|---|
| Evidence that long term soil fertility can be enhanced by poultry litter. | 4 | 3 | 2 | 1 |
| Dealer assurance of the nitrogen content of composted poultry litter. | 4 | 3 | 2 | 1 |
| Cash payment of $25.00 for each acre on which 1 ton of poultry litter is applied and nitrogen fertilizer is reduced by 35 pounds. | 4 | 3 | 2 | 1 |
| A 10 cent per pound increase in the price of nitrogen fertilizer. | 4 | 3 | 2 | 1 |

24. Suppose you were seeking more information on the alternative approaches for supplying nitrogen described in the previous questions. How reliable would you consider the following information sources?

| | VERY RELIABLE | | | NOT VERY RELIABLE |
|---|---|---|---|---|
| LOCAL EXTENSION AGENT | 4 | 3 | 2 | 1 |
| VA TECH EXTENSION SPECIALISTS AT BLACKSBURG | 4 | 3 | 2 | 1 |
| FARM MAGAZINES | 4 | 3 | 2 | 1 |
| AGRICULTURAL SUPPLY COMPANIES | 4 | 3 | 2 | 1 |
| OTHER FARMERS | 4 | 3 | 2 | 1 |

Finally, we would like to ask a few questions specifically about you to help us interpret the results. This information will only be used for statistical summaries.

25. What is your age?

_____ 19 - 24 YEARS
_____ 25 - 34 YEARS
_____ 35 - 44 YEARS
_____ 45 - 54 YEARS
_____ 55 - 64 YEARS
_____ 65 - 74 YEARS
_____ 75 YEARS OR OVER

26. Which is the highest level of education that you have completed?

_____ 8th GRADE OR UNDER
_____ 9th GRADE THROUGH 11th GRADE
_____ COMPLETED HIGH SCHOOL
_____ SOME COLLEGE
_____ COMPLETED COLLEGE
_____ SOME GRADUATE WORK
_____ A GRADUATE DEGREE

27. How many years have you been farming? (check one)

_____ LESS THAN 5 YEARS
_____ 6 TO 10 YEARS
_____ 11 TO 20 YEARS
_____ 21 TO 30 YEARS
_____ MORE THAN 30 YEARS

28. How many persons (excluding yourself) will work on your farm in 1988? (Assume full time is 40 hours per week on average, part time is 20 hours per week on average.)

| | NUMBER OF PERSONS |
|---|---|
| Full time, year round | _____ |
| Part time, year round | _____ |
| ADDITIONAL LABOR | |
| Spring - full time | _____ |
| Spring - part time | _____ |
| Fall - full time | _____ |
| Fall - part time | _____ |

29. Will you or your spouse be employed off the farm in 1988?

| YOURSELF | YOUR SPOUSE |
|---|---|
| _____ YES, FULL TIME | _____ YES, FULL TIME |
| _____ YES, 3/4 TIME | _____ YES, 3/4 TIME |
| _____ YES, 1/2 TIME | _____ YES, 1/2 TIME |
| _____ YES, 1/4 TIME | _____ YES, 1/4 TIME |
| _____ NO | _____ NO |

30. In an average year, what percent of your total household income comes from farming?

_____ PERCENT

31. Over the next 10 years, do you plan to: (check one)

_____ CONTINUE FARMING
_____ RETIRE FROM FARMING AND RENT OUT YOUR LAND
_____ RETIRE FROM FARMING AND RETIRE THE LAND
_____ PASS FARM OPERATION ON TO A CHILD OR OTHER RELATIVE
_____ SELL YOUR FARM

☐ Please send information on alternative nitrogen approaches for my farm.

---

If there is anything else you would like to tell us about concerns and issues in Virginia agriculture, please use this space to do so.

Also, any comments you may have concerning this survey are appreciated.

Your time and assistance are greatly appreciated. If you would like a summary of the results, please print your name and address on the back of the return envelope (NOT on the questionnaire). We will see that you get a copy.

A.B. Farmer
Route 1, Box 00
Eastern, VA  24680

Dear A.B. Farmer:

We are all aware of the importance of agriculture to Virginia's economy. As you may know, Governor Baliles has made improved profitability in agriculture one of his top priorities. In response, Virginia Tech's Department of Agricultural Economics hopes to initiate a strategic planning program for its research and extension activities to provide reliable information to assure the improved use of rural resources and an improved agricultural economy.

As part of this initiative, the Department of Agricultural Economics is investigating alternative approaches for reducing production costs and improving the profit situation of Virginia farmers. To aid our investigations, we are seeking the views of agricultural producers. As a Virginia farmer, you have been chosen to participate in this important survey.

<u>If you own farm land but do not farm it yourself, do not complete the survey. Just return the survey form to us in the enclosed, pre-paid envelope.</u>

If you are farming, we would like to hear your views about different approaches for providing nitrogen to crops. At the end of the survey, you may request more information on alternative nitrogen fertilization strategies. Once you have completed the survey, just check the box at the end of the questionnaire requesting additional information, and it will be sent to you in the near future. Then, return the completed survey form in the enclosed, pre-paid envelope. We assure that your responses will remain confidential.

Thank you for your time and assistance. If you have questions about the study or the questionnaire, please feel free to call Patricia Norris at .

Sincerely,

| | |
|---|---|
| Patricia Norris<br>Project Assistant | Leonard Shabman<br>Professor |

April 13, 1988

Two weeks ago a questionnaire was mailed to you that asked for your views about alternative approaches for providing nitrogen to crops. If you have already completed the questionnaire and returned it, please accept our thanks. If not, we would appreciate your returning it to us today.

Researchers in the Department of Agricultural Economics at Virginia Tech are interested in developing strategies to help farmers decrease production costs by decreasing the amount of nitrogen fertilizer they purchase. Your response is important to help us accurately assess the opinions and information needs of Virginia farmers. Please fill out the survey and let us know your views.

If you did not receive a survey or it has been misplaced, you will receive another one in about 2 weeks.

Thanks again for your help.

Sincerely,

Patricia Norris
Project Assistant

A.B. Farmer
Route 1, Box 00
Eastern, VA 24680

Dear A.B. Farmer:

About three weeks ago, we sent you a survey on alternative nitrogen sources for agriculture in Virginia. As of today, we have not yet received your completed questionnaire. We are writing to you again because your response is important to us as we investigate alternative approaches for reducing production costs and improving the profit situation of Virginia farmers.

We assure complete confidentiality. The return envelope has an identification number on it for mailing purposes only. A student will check off your name when the survey is returned. The envelope with the identification number will be discarded immediately. Your name will never be placed on the survey, and it will be impossible to trace responses back to any individual.

<u>If you own farm land but do not farm it yourself, do not complete the survey. Just return the survey form to us in the enclosed, pre-paid envelope.</u>

If you are farming, we would like to hear your views about different approaches for providing nitrogen to crops. At the end of the survey, you may request more information on alternative nitrogen fertilization strategies. Once you have completed the survey, just check the box at the end of the questionnaire requesting additional information, and it will be sent to you in the near future. Then, return the completed survey form in the enclosed, pre-paid envelope.

In the event your survey has been misplaced, a replacement copy is enclosed. If you have already completed the survey and returned it, please accept our thanks. If not, we would appreciate you returning it to us today. Again, thank you for your time and assistance. If you have questions about the study or the questionnaire, please feel free to call Patricia Norris at .

Sincerely,

| | |
|---|---|
| Patricia Norris<br>Project Assistant | Leonard Shabman<br>Professor |

# Appendix E. Survey Data Used for Logit Analysis

Appendix E. Survey Data Used for Logit Analysis

| OBS | SPLITN | SPRA1 | SPRA2 | EDUC1 | EDUC2 | EDUC3 | EDUC4 | COMP | CPXSPL | FP | INFO | COMMUN | ENVIR | CHANGE | SIZE | LEGN | LGRA1 | LGRA2 | CPXLEG | PLAN | TAXS | PAYS | TAXL | PAYL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 2 | 3 | 0 | 0 | 0 | 1 | 1 | 3 | 1 | 0 | 1 | 6 | 9 | 3687.0 | 1 | 1 | 3 | 4 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 4 | 0 | 0 | 1 | 0 | 1 | 4 | 0 | 1 | 1 | 4 | 7 | 400.0 | 0 | 3 | 3 | 4 | 1 | . | . | 1 | 1 |
| 3 | 0 | 4 | 2 | 0 | 1 | 0 | 0 | 1 | 2 | 0 | 1 | 1 | 8 | 7 | 150.0 | 1 | 2 | 4 | 6 | 1 | 1 | 1 | . | . |
| 4 | 0 | 3 | 1 | 0 | 0 | 0 | 0 | 1 | 3 | 1 | 0 | 0 | 5 | 3 | 1200.0 | 0 | 1 | 3 | 6 | 1 | 0 | 0 | . | . |
| 5 | 0 | . | . | 0 | 0 | 0 | 1 | 1 | . | 0 | 1 | 2 | . | . | 522.0 | 0 | . | . | . | 1 | . | . | . | . |
| 6 | 1 | 2 | 4 | 0 | 0 | 0 | 1 | 1 | 3 | 0 | 1 | 4 | 5 | 7 | 1330.0 | 1 | 3 | 2 | 4 | 1 | . | . | 1 | 1 |
| 7 | 0 | 3 | 2 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 6 | 8 | 1112.0 | 0 | 4 | 2 | 3 | 0 | 0 | 1 | 0 | 0 |
| 8 | 0 | 1 | 4 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 5 | 9 | 67.0 | 1 | 1 | 4 | 8 | 0 | . | . | . | . |
| 9 | 0 | . | . | 0 | 1 | 0 | 0 | 1 | . | 1 | 1 | . | . | . | 239.0 | 1 | . | . | . | 1 | . | . | . | . |
| 10 | 1 | 2 | 3 | 0 | 0 | 1 | 0 | 1 | 3 | 0 | 0 | 1 | 7 | 6 | 750.0 | 1 | 1 | 4 | 7 | 1 | . | . | . | . |
| 11 | 0 | 4 | 4 | 0 | 0 | 0 | 0 | 1 | . | 0 | 0 | 1 | . | 12 | 50.0 | 0 | 3 | 4 | 4 | 1 | 0 | 1 | 0 | 1 |
| 12 | 1 | 2 | 3 | 1 | 0 | 0 | 0 | 1 | 3 | 1 | 0 | 0 | 6 | 8 | 540.0 | 0 | 3 | 3 | 4 | 1 | . | . | 1 | 1 |
| 13 | 1 | 4 | 1 | 1 | 0 | 0 | 0 | 1 | 4 | 0 | 1 | 2 | 2 | 10 | 5300.0 | 1 | 3 | 4 | 2 | 1 | 0 | 1 | 1 | 1 |
| 14 | 0 | 2 | 4 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 3 | 7 | 58.0 | 0 | 2 | 3 | 5 | 1 | 1 | 1 | 1 | 1 |
| 15 | 1 | 2 | 3 | 1 | 0 | 0 | 0 | 1 | 3 | 1 | 1 | 1 | 4 | 6 | 300.0 | 0 | 2 | 4 | 5 | 1 | . | . | 0 | 1 |
| 16 | 1 | 1 | 4 | 1 | 0 | 0 | 0 | 1 | 3 | 0 | 1 | 1 | 5 | 6 | 541.0 | 0 | 2 | 3 | 6 | 1 | . | . | 1 | 1 |
| 17 | . | . | . | 0 | 0 | 0 | 0 | 0 | . | 0 | . | . | . | . | 17.0 | . | . | . | . | 0 | . | . | . | . |
| 18 | 1 | 2 | 4 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 1 | 1 | 6 | 8 | 300.0 | 0 | 2 | 3 | 5 | 1 | . | . | 0 | 1 |
| 19 | 1 | 1 | 3 | 0 | 1 | 0 | 0 | 1 | 3 | 0 | 1 | 4 | 7 | . | 1400.0 | 1 | 1 | 3 | 3 | 1 | . | . | . | . |
| 20 | 0 | 3 | 4 | 0 | 1 | 0 | 0 | 0 | 3 | 1 | 0 | 1 | 5 | 5 | 616.0 | 0 | 3 | 4 | 5 | 1 | 0 | 0 | 0 | 0 |
| 21 | 1 | . | 3 | 0 | 0 | 0 | 1 | 1 | 3 | 0 | 0 | 1 | . | 8 | 67.0 | . | 1 | . | 6 | 1 | . | . | . | . |
| 22 | 1 | 1 | 4 | 1 | 0 | 0 | 0 | 1 | 4 | 1 | 1 | 2 | 5 | 9 | 75.0 | 0 | 2 | 4 | 3 | 1 | . | . | 1 | 1 |
| 23 | 1 | 1 | 3 | 1 | 0 | 0 | 0 | 1 | 2 | 1 | 0 | 1 | 4 | 3 | 450.0 | 0 | 2 | 3 | 5 | 1 | . | . | 0 | 1 |
| 24 | 0 | 1 | 4 | 0 | 1 | 0 | 0 | 1 | 2 | 0 | 1 | 1 | 5 | 6 | 360.0 | 0 | 2 | 4 | 4 | 1 | . | . | 0 | 1 |
| 25 | 0 | 3 | 4 | 1 | 0 | 0 | 0 | 1 | 3 | 0 | 1 | 1 | 4 | 5 | 570.0 | 0 | 3 | 3 | 4 | 1 | 1 | 1 | 1 | 1 |
| 26 | 1 | 1 | 4 | 1 | 0 | 0 | 0 | 1 | 3 | 1 | 0 | 1 | 4 | 3 | 700.0 | 1 | 1 | 4 | 8 | 0 | . | . | . | 1 |
| 27 | 0 | 1 | 4 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 0 | 1 | 6 | 7 | 75.0 | 0 | 1 | 4 | 7 | 1 | 1 | 0 | 1 | 1 |
| 28 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 6 | 12 | 12.0 | 1 | . | 4 | 8 | 0 | 0 | 0 | 0 | 0 |
| 29 | 0 | 4 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 2 | 5 | 5 | 42.0 | 0 | 1 | 4 | 3 | 0 | 1 | 1 | 1 | 1 |
| 30 | 1 | 3 | 3 | 1 | 0 | 0 | 0 | 1 | 3 | 0 | 1 | 1 | 8 | 10 | 450.0 | 0 | 3 | 3 | 6 | 1 | 1 | 1 | 1 | 1 |
| 31 | 1 | 2 | 4 | 1 | 0 | 0 | 0 | 1 | 3 | 0 | 0 | 1 | 7 | 6 | 600.0 | 1 | 1 | 3 | 6 | 1 | 1 | 1 | 1 | 1 |
| 32 | 0 | 4 | 3 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 0 | 1 | 5 | 7 | 2100.0 | 0 | 4 | 4 | 7 | 0 | 0 | 0 | 0 | 1 |
| 33 | 0 | . | . | 0 | 0 | 0 | 0 | 1 | . | 1 | 0 | . | . | . | 335.0 | 0 | . | . | . | 0 | . | . | . | . |
| 34 | 1 | 3 | 2 | 0 | 1 | 0 | 0 | 1 | 2 | 1 | 1 | 1 | 4 | 8 | 1300.0 | 0 | 2 | 4 | 4 | 1 | 0 | 0 | 0 | 0 |
| 35 | 1 | 1 | 3 | 0 | 0 | 0 | 1 | 1 | 2 | 1 | 0 | 3 | 5 | 6 | 511.0 | 1 | 2 | 3 | 5 | 1 | . | . | 1 | 1 |
| 36 | 1 | 3 | 3 | 0 | 0 | 0 | 0 | 1 | 3 | 1 | 0 | 1 | 8 | . | 18.0 | 0 | 1 | 4 | 8 | 0 | 0 | 0 | 0 | 1 |
| 37 | 1 | 2 | 3 | 0 | 0 | 0 | 1 | 0 | 3 | 0 | 1 | 2 | 6 | 8 | 2.5 | 0 | 3 | 3 | 6 | 1 | . | . | 1 | 1 |
| 38 | 0 | 2 | 2 | 0 | 0 | 1 | 0 | 1 | 2 | 0 | 0 | 1 | 3 | 6 | 0.5 | 0 | 3 | 2 | 5 | 0 | 1 | 0 | 0 | 0 |
| 39 | 1 | 1 | 4 | 0 | 0 | 0 | 0 | 1 | 4 | 0 | 0 | 1 | . | . | 620.0 | 1 | 1 | 4 | 6 | 1 | . | . | . | . |
| 40 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 1 | 4 | 9 | 130.0 | 1 | 1 | 3 | 6 | 1 | 0 | 1 | . | . |
| 41 | . | . | . | 0 | 0 | 0 | 0 | 1 | . | 0 | 0 | . | . | . | 690.0 | . | . | . | . | 0 | . | . | . | . |
| 42 | 1 | 2 | 3 | 1 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 2 | 8 | 7 | 208.0 | 0 | . | 3 | 5 | 1 | . | . | 1 | 1 |
| 43 | 0 | 4 | 1 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 0 | 0 | 6 | 3 | 358.5 | 0 | 2 | 4 | 4 | 1 | 0 | 1 | 0 | 1 |
| 44 | 0 | 3 | 3 | 0 | 0 | 1 | 0 | 1 | 3 | 0 | 1 | 0 | 6 | 7 | 342.0 | 0 | 2 | 3 | 4 | 1 | 1 | 1 | 1 | 1 |
| 45 | 0 | 3 | 3 | 1 | 0 | 0 | 0 | 1 | 3 | 0 | 0 | 1 | 4 | 7 | 540.0 | 0 | 1 | 4 | . | 0 | . | 1 | . | 1 |
| 46 | 1 | 3 | 4 | 1 | 0 | 0 | 0 | 1 | 2 | 0 | 1 | 1 | 2 | 11 | 150.0 | 0 | 1 | 1 | 2 | 1 | . | . | 0 | 0 |
| 47 | 0 | 3 | 3 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 1 | 0 | 4 | 9 | 261.0 | 0 | 4 | 3 | 2 | 1 | 0 | 1 | 1 | 1 |
| 48 | 1 | 2 | 4 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 1 | 1 | 2 | 6 | 100.0 | 0 | 3 | 3 | 5 | 1 | . | . | 1 | 1 |
| 49 | 0 | 4 | 4 | 0 | 0 | 0 | 0 | . | . | 0 | 0 | 0 | 2 | 4 | . | 1 | . | . | . | 1 | . | . | . | . |
| 50 | 1 | 1 | 3 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 1 | 1 | 8 | 10 | 25.0 | 0 | 3 | 3 | 5 | 1 | . | . | 0 | 1 |

| OBS | SPLITN | SPRA1 | SPRA2 | EDUC1 | EDUC2 | EDUC3 | EDUC4 | COMP | CPXSPL | FP | INFO | COMMUN | ENVIR | CHANGE | SIZE | LEGN | LGRA1 | LGRA2 | CPXLEG | PLAN | TAXS | PAYS | TAXL | PAYL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 | 0 | 4 | 3 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 1 | 0 | 4 | 9 | 58.0 | 0 | 2 | 2 | 6 | 1 | 1 | 1 | 1 | 1 |
| 52 | 1 | 3 | 3 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 1 | . | 2 | 9 | 12.0 | 1 | 3 | 3 | 4 | 1 | . | . | . | . |
| 53 | . | . | . | 0 | 0 | 0 | 0 | 0 | . | 1 | 0 | 0 | 8 | 3 | 93.0 | . | 1 | 4 | . | 1 | . | . | 0 | 1 |
| 54 | 0 | . | . | 0 | 0 | 0 | 0 | 1 | . | 0 | 0 | 0 | . | . | 102.0 | 1 | . | . | . | 1 | . | . | . | . |
| 55 | 0 | 4 | 4 | 1 | 0 | 0 | 0 | 1 | 4 | 1 | 1 | 2 | 2 | 3 | 348.0 | 0 | 2 | 4 | 3 | 0 | . | 1 | . | 1 |
| 56 | 0 | 3 | 4 | 1 | 0 | 0 | 0 | 1 | 3 | 0 | 0 | 1 | 8 | 10 | 350.0 | 0 | 2 | 4 | 5 | 0 | 1 | 1 | 0 | 0 |
| 57 | 0 | 2 | 3 | 1 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 1 | 5 | 7 | 50.0 | 0 | 3 | 3 | 6 | 0 | 1 | 1 | 1 | 1 |
| 58 | 1 | 4 | 3 | 1 | 0 | 0 | 0 | 1 | 3 | 0 | 0 | 0 | 7 | 9 | 666.0 | 0 | 3 | 3 | 5 | 1 | . | . | 0 | 1 |
| 59 | 1 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 1 | 3 | 3 | 80.0 | 0 | 2 | . | . | 0 | . | . | 1 | 1 |
| 60 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 7 | 9 | 73.0 | 0 | 4 | 3 | 6 | 0 | 0 | 0 | 0 | 1 |
| 61 | . | . | . | 0 | 0 | 0 | 0 | 1 | . | 0 | 0 | . | . | . | 235.0 | . | . | . | . | 0 | . | . | . | . |
| 62 | 0 | 4 | 1 | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 2 | 2 | 5 | 527.0 | 0 | 1 | 4 | 4 | 0 | 0 | 1 | 0 | 1 |
| 63 | 1 | 1 | 4 | 1 | 0 | 0 | 0 | 1 | 4 | 0 | 0 | 1 | 4 | 8 | 75.0 | 0 | 1 | 4 | 7 | 0 | . | . | 1 | 1 |
| 64 | 0 | 4 | 3 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 2 | 6 | 855.0 | . | . | . | . | 1 | . | 1 | . | . |
| 65 | . | . | . | 0 | 0 | 0 | 0 | 1 | . | 0 | 0 | . | . | . | 287.0 | . | . | . | . | 0 | . | . | . | . |
| 66 | 0 | 2 | 4 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 8 | 9 | 50.0 | 0 | 2 | 2 | 3 | 1 | 0 | 1 | 0 | 1 |
| 67 | 1 | 1 | 4 | 1 | 0 | 0 | 0 | 1 | 2 | 1 | 0 | 1 | 2 | 3 | 348.0 | 0 | 1 | 4 | 7 | 0 | 0 | 1 | 1 | 1 |
| 68 | 1 | 2 | 4 | 1 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 1 | 7 | 6 | 160.0 | 0 | 2 | 4 | 5 | 1 | 0 | 1 | 0 | 1 |
| 69 | 0 | 4 | 2 | 1 | 0 | 0 | 0 | 1 | 3 | 1 | 1 | 2 | 4 | 6 | 1100.0 | 1 | 1 | 4 | 5 | 1 | 1 | 1 | . | . |
| 70 | 0 | 4 | 4 | 0 | 0 | 0 | 0 | 1 | 4 | 1 | 1 | 1 | 8 | 6 | 401.0 | 0 | 4 | 4 | 8 | 0 | 0 | 1 | 0 | 1 |
| 71 | . | . | . | 0 | 0 | 0 | 0 | 0 | . | 0 | . | . | . | . | 85.0 | . | . | . | . | 0 | . | . | . | . |
| 72 | . | . | . | 0 | 0 | 0 | 0 | 0 | . | 0 | . | . | . | . | 110.0 | . | . | . | . | 0 | . | . | . | . |
| 73 | 1 | 4 | 4 | 0 | 0 | 0 | 1 | 1 | 4 | 1 | 0 | 2 | 6 | 7 | 900.0 | 0 | 4 | 4 | 5 | 1 | . | . | 1 | 1 |
| 74 | 1 | 2 | 3 | 0 | 0 | 0 | 1 | 1 | 3 | 1 | 0 | 3 | 5 | 6 | 130.0 | 0 | 3 | 3 | 2 | 1 | 1 | 1 | 0 | 1 |
| 75 | 0 | 3 | 4 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 1 | 0 | 8 | 11 | 11.5 | 0 | 2 | 4 | 7 | 1 | 0 | 0 | 0 | 1 |
| 76 | 0 | 3 | 4 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 0 | 1 | 5 | 6 | 945.0 | 0 | 2 | 3 | 4 | 0 | 1 | 1 | 0 | 1 |
| 77 | 1 | 1 | 4 | 1 | 0 | 0 | 0 | 1 | 3 | 1 | 1 | 2 | 6 | 8 | 2465.0 | 0 | 3 | 4 | 5 | 1 | . | . | 1 | 1 |
| 78 | 0 | 2 | 3 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 1 | 1 | 6 | 9 | 700.0 | 0 | 4 | 4 | 7 | 1 | 1 | 1 | 1 | 1 |
| 79 | 1 | . | . | 0 | 0 | 0 | 0 | 1 | . | 0 | 0 | 1 | . | . | 204.0 | 0 | . | . | . | 0 | . | . | . | . |
| 80 | . | . | . | 0 | 0 | 0 | 0 | 0 | . | 0 | . | . | . | . | 80.0 | . | . | . | . | 0 | . | . | . | . |
| 81 | 0 | 2 | . | 0 | 1 | 0 | 0 | 1 | 3 | 0 | 1 | 0 | 4 | 6 | 270.0 | 0 | 2 | 3 | . | 1 | 0 | 1 | 0 | 1 |
| 82 | 1 | 1 | 4 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | . | . | 77.0 | 0 | 4 | 3 | 4 | 1 | . | . | 0 | 1 |
| 83 | . | . | . | 0 | 0 | 0 | 0 | 0 | . | 0 | . | . | . | . | 25.0 | . | . | . | . | 0 | . | . | . | . |
| 84 | 1 | 2 | 4 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 7 | 3 | 214.0 | 0 | 3 | 4 | 5 | 1 | . | . | 1 | 1 |
| 85 | 0 | 3 | 3 | 1 | 0 | 0 | 0 | 1 | 3 | 1 | 0 | 1 | 3 | 3 | 235.0 | 0 | 2 | 3 | 4 | 1 | 0 | 1 | 1 | 1 |
| 86 | 1 | 1 | 4 | 0 | 0 | 1 | 0 | 1 | 3 | 0 | 1 | 1 | 3 | 7 | 535.0 | 0 | 3 | 4 | 5 | 0 | . | . | 1 | 1 |
| 87 | 0 | 1 | 2 | 0 | 1 | 0 | 0 | 1 | 2 | 0 | 1 | 0 | 2 | 6 | 1000.0 | 0 | 1 | 1 | 2 | 0 | 1 | 1 | 1 | 1 |
| 88 | 1 | 2 | 4 | 0 | 0 | 1 | 0 | 1 | 4 | 1 | 1 | 2 | 5 | 10 | 260.0 | 0 | 4 | 3 | 3 | 0 | . | . | . | 1 |
| 89 | 0 | 4 | 4 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 7 | 6 | 61.0 | 0 | 2 | 2 | 4 | 1 | 0 | 0 | 0 | 0 |
| 90 | . | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | . | 5 | 9 | 40.0 | 0 | 4 | 1 | 8 | 1 | . | . | 0 | . |
| 91 | 0 | 2 | 3 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 1 | 2 | 4 | 8 | 115.0 | 0 | 2 | 3 | 3 | 1 | 1 | 1 | 1 | 1 |
| 92 | 1 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 3 | 1 | 0 | 0 | . | . | 198.0 | 1 | . | 4 | 6 | 1 | . | . | . | 0 |
| 93 | 0 | 3 | 2 | 1 | 0 | 0 | 0 | 1 | 2 | 1 | 1 | 1 | 6 | 7 | 323.0 | 1 | 2 | 4 | 4 | 0 | 1 | 1 | 1 | 1 |
| 94 | . | . | . | 0 | 0 | 0 | 0 | 0 | . | 0 | . | . | . | . | 25.0 | . | . | . | . | 0 | . | . | . | . |
| 95 | 0 | 3 | 3 | 0 | 0 | 1 | 0 | 0 | 4 | 0 | 1 | 3 | 4 | 8 | 52.0 | 1 | 2 | 1 | 5 | 0 | 1 | 1 | 1 | 1 |
| 96 | 1 | 3 | 1 | 0 | 0 | 0 | 1 | 1 | 4 | 1 | 1 | 3 | 4 | 10 | 354.0 | 0 | 3 | 1 | 3 | 1 | . | . | 1 | 1 |
| 97 | 1 | 1 | 4 | 0 | 1 | 0 | 0 | 1 | 4 | 1 | 1 | 2 | 7 | 8 | 72.0 | 1 | 2 | 4 | 6 | 1 | . | . | 1 | 1 |
| 98 | 0 | 4 | 3 | 1 | 0 | 0 | 0 | 1 | 3 | 0 | 1 | 2 | 8 | 5 | 150.0 | 0 | 2 | 4 | 6 | 1 | 1 | 1 | 0 | 1 |
| 99 | 1 | 4 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 2 | 4 | 68.0 | 0 | 4 | 2 | 3 | 0 | 0 | 0 | 0 | 0 |
| 100 | 0 | 3 | 1 | 0 | 0 | 0 | 1 | 0 | 2 | 1 | 0 | 1 | 7 | . | 140.0 | 0 | 2 | 3 | 7 | 0 | . | . | 1 | 1 |

| OBS | SPLITN | SPRA1 | SPRA2 | EDUC1 | EDUC2 | EDUC3 | EDUC4 | COMP | CPXSPL | FP | INFO | COMMUN | ENVIR | CHANGE | SIZE | LEGN | LGRA1 | LGRA2 | CPXLEG | PLAN | TAXS | PAYS | TAXL | PAYL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | 0 | 2 | 2 | 1 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 1 | 2 | 10 | 1000 | 0 | 2 | 3 | 5 | 0 | 1 | 1 | 0 | 1 |
| 102 | 0 | 3 | 3 | 1 | 0 | 0 | 0 | 1 | 2 | 0 | 1 | 1 | 6 | 7 | 125 | 0 | 3 | 3 | 6 | 1 | 1 | 1 | 1 | 1 |
| 103 | 0 | 3 | 4 | 0 | 1 | 0 | 0 | 1 | 3 | 0 | 1 | 1 | 4 | 8 | 739 | 0 | 3 | 4 | 6 | 0 | 1 | 1 | 1 | 1 |
| 104 | . | . | . | 0 | 0 | 0 | 1 | 0 | . | 1 | 0 | . | 6 | 12 | 56 | . | . | . | . | 0 | . | . | . | . |
| 105 | 0 | 4 | 1 | 1 | 0 | 0 | 0 | 1 | 3 | 0 | 1 | 1 | 4 | 5 | 200 | . | 2 | 2 | 3 | 1 | 1 | 0 | 0 | 1 |
| 106 | 1 | 3 | 2 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 2 | 8 | 11 | 450 | 0 | 3 | 4 | 6 | 0 | . | . | 0 | 1 |
| 107 | . | . | . | 0 | 0 | 0 | 0 | 0 | . | 0 | . | . | . | . | 1666 | . | . | . | . | 0 | . | . | . | . |
| 108 | 0 | 2 | 4 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 1 | 1 | 5 | 4 | 324 | 0 | 1 | 4 | 5 | 1 | 0 | 1 | 1 | 1 |
| 109 | 1 | 3 | 4 | 0 | 0 | 0 | 1 | 1 | 3 | 1 | 1 | 1 | 5 | 8 | 852 | 1 | 3 | 4 | 6 | 0 | . | . | 1 | 1 |
| 110 | 1 | 1 | 4 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 6 | 8 | 2250 | 0 | 3 | 3 | 5 | 1 | . | . | 0 | 0 |
| 111 | 1 | 3 | 4 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 3 | 2 | 5 | 271 | 0 | 2 | 3 | 5 | 1 | . | . | 1 | 1 |
| 112 | 1 | 1 | 4 | 0 | 1 | 0 | 0 | 1 | 4 | 1 | 1 | 4 | 8 | 8 | 600 | 1 | 2 | 4 | 3 | 1 | . | . | . | . |