A Farm-Level Evaluation of Agricultural Profit and Ground Water Quality: Texas Seymour Aquifer

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ABSTRACT

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The Seymour Aquifer of north-central Texas is known to have elevated levels of nitrates. The design of economically sound policies for reducing agriculture's nitrate contribution to the aquifer suggests a need to evaluate alternative management practices and implications of different policies on nitrate percolation and associated loss of net returns.

In the absence of field and experimental data, a validated process model (EPIC-WQ) was used to simulate crop yield and nitrate percolation by using stochastic weather and by varying the quantity and timing of nitrogen and irrigation applications across two soil types and tillage practices. Using these simulated data, a set of response functions was estimated and incorporated inside a risk-sensitive farm-level optimization model. Various policy instruments such as a performance standard, design standard, performance tax, performance subsidy, nitrogen tax, and nitrogen subsidy were evaluated to determine the economic and environmental tradeoffs for the region.

A performance standard or a design standard (obtained from the model solution of performance standard) will decrease farm net income (over variable cost) by $6,220 or $5,225 for risk neutral and risk averse case, respectively. Arbitrarily selected design standards such as split use of fertilizer and minimum tillage reduced percolation but not down to 10 ppm. The net income loss for a performance tax was $17,340 and $15,233 for the two risk behavior scenarios, respectively. A performance subsidy would increase net income (subsidy received minus abatement cost) by $452 and $784 for risk neutral and risk averse case, respectively. A nitrogen tax of 200% of the purchase price of nitrogen caused a $29,680 and $36,910 reduction in net income while a nitrogen subsidy increased net income (subsidy received minus abatement cost) by $4,474 and $8,285, respectively.

For the whole region, the least costly policy alternative would cost approximately $1 million either as farm net income loss or as government subsidy. Comparing this cost with the cost of bottled water (used as a proxy for the loss of consumer surplus) shows that this cost is about three times the cost of bottled water.

Dedicated to my wife Sonia

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CHAPTER I

INTRODUCTION

Potable groundwater is one of the most limiting natural resources in the Western United States. Demographic changes and new development in arid regions, changes in water law, declining groundwater supplies, reductions in federal spending, and increased state controls over water management are causing changes in the way groundwater is used, priced, and allocated. Complicating the quantity of available water supplies is the ever-increasing threat of contamination of groundwater from municipal, industrial, and agricultural activities. Concerns directed to agriculture and water quality relate primarily to sediment runoff and fertilizer and pesticide use.

In the U.S., groundwater is the source of drinking water for 50% of the population and 97% of the rural population (Olsenius). Groundwater withdrawals are increasing at double the rate of increase for surface water use, with half a million new well drilled each year (Henderson et al.). About 50 million people rely on groundwater in areas identified as vulnerable to agricultural groundwater pollution (Lee and Nielsen). While the actual amount of contaminated groundwater is not alarmingly high (Page), concern for groundwater contamination is a priority given the potential threat to human health and the economic costs associated with making contaminated water potable.

Although groundwater contamination has many sources, evidence suggests that agriculture's relative contribution may be significant. Incidents of groundwater contamination from the leaching of agricultural pesticides and fertilizers have been documented in many parts of the nation, including Pennsylvania, Florida, Wisconsin, California, New York, and Iowa (Cohen; Hallberg 1984; Hebb and Wheeler; Jones

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This dissertation follows the style and format of the *American Journal of Agricultural Economics.*

and Back; Kim et al.; Pionke and Urban; Rhodes; Rothschild et al.; Zaki et al.; Zaporozec). A 1985 survey showed that 34 states reported groundwater contamination by nitrate and four more states reported suspected contamination (Association of State and Interstate Water Pollution Control Agencies). These findings are not surprising since approximately 330 million acres of farm land were being cultivated using intensive production systems in 1987 (Moody; Swanson, Camboni, and Napier). A large proportion of this cultivated land has been in crop production for decades.

The use of inorganic nitrogen fertilizers, a major source of nitrate-nitrogen contamination of groundwater, increased 11-fold between 1950 and 1980 (Lee and Nielsen). The per acre rate of nitrogen use doubled between 1965 and 1984 (U.S. Department of Agriculture 1985). Along with inorganic fertilizer, agricultural use of pesticides rose sharply, nearly tripling from 1964 to 1984 (U.S. Environmental Protection Agency).

An example of fertilizer use and groundwater quality degradation has recently been documented in the Platte Valley in central Nebraska (Schepers et al.). The study involving some 3,900 fields under irrigated corn production covering 208,000 acres found a strong positive correlation between nitrogen fertilizer application rate and nitrate in groundwater. The results of this study suggest over-fertilization in the study area, resulting in elevated nitrate concentration in groundwater without the benefit of enhanced yields.

Agricultural nonpoint pollution has received less scrutiny than other resource and environmental concerns during the 1970s and 1980s. With the exception of pesticides, much early attention by the EPA and other regulatory agencies centered on point-source pollution i.e. industrial, municipal, and transportation pollutants. Point source pollutants received primary emphasis because (i) a belief that sufficient pollution control could be achieved by managing only point sources of pollution and (ii) an understanding that pollutant-load reductions could be achieved more economically by controlling point sources. In recent years, however, the emphasis has gradually shifted to nonpoint source pollution. The Water Quality Act of 1987, farm program provisions of 1985 and 1990, the Safe Drinking Water Act, and the Federal Insecticide, Fungicide, and Rodenticide Act show renewed emphasis on the impact of agricultural practices on water quality. The following brief overview of these legislations shows the recognition of the problem of water quality degradation and emphasis on more information gathering, technical support, and voluntary action.

Section 208 of the U.S. Federal Water Pollution Control Act Amendments of 1972, Public Law No. 92-500, requires states to develop nonpoint-source plans with the realization that groundwater and potential sources of contamination differ from state to state, making it impractical to establish a uniform federal program (Braden and Uchtmann). With the exception of few states, every state has created voluntary programs for reducing nonpoint pollution from agriculture. The Food Security Act of 1985, commonly called the 1985 Farm Bill, combined conservation and environmental objectives with commodity price and production objectives. Most of the emphasis in the 1985 Farm Bill, however, emphasized "on site" provisions - how conservation compliance would benefit the individual farmer from a productivity standpoint.

The President's Water Quality Initiative of 1988 gave agricultural agencies the opportunity to define and demonstrate the environmentally acceptable Best Management Practices (BMPs) that maintain farm economic viability and reduce point and nonpoint-source water pollution. Selected water quality sensitive areas related to agriculture were defined for demonstrating the BMPs. Two designations for addressing water quality issues in agriculture were Demonstration Projects and Hydrologic Unit Areas (HUAs), which are part of the local nonpoint-source plans and typically involve cooperative efforts by local, state, and federal agencies.

The Food, Agricultural, Conservation, and Trade Act (FACTA) or the 1990 Farm Bill enacted new provisions dealing with water quality and other environmental topics. Of the numerous provisions in FACTA dealing with water quality, the most notable was a new Agricultural Water Quality Protection Program (WQPP) set forth in Title XIV (Section 1439) (Cohen et al.). It created provisions for agricultural producers in environmentally sensitive areas to request assistance to develop and implement on-farm water quality protection plans to assist in compliance with State and Federal environmental laws. In addition, the 1990 Farm Bill gave increased priority to water quality across all USDA agencies through the newly created Agricultural Council on Environmental Quality and the Office of Environmental Quality, and the Agriculture and Water Policy Coordination Act.

This history of federal policies shows that actions directed at controlling agricultural nonpoint pollution have been voluntary in nature. Moral suasion, education, and technical assistance have been the major instruments used by the local, state, and federal governments. Recognizing the importance of information, technical assistance, and moral suasion, there may be cases where dependence on pure voluntary measures is not adequate. Once some relationship between agricultural activities and water quality is established for an watershed, various mandatory and incentive based policy options or a mixture of assistance, mandatory provisions, and incentives can be analyzed along with the pure voluntary approach. Currently, 11 states combine voluntary measures with regulatory provisions for reducing nonpoint pollution from agriculture (Braden and Uchtmann).

The design of these policies for reducing nitrogen losses from farming activities requires consideration of how farmers may respond to alternative policy approaches and the farmer's costs of control. For example, reduction of nitrate leaching from a policy may require modification of farmers' management practices that, in turn, may lead to reduced profits. Quantification of these potential economic and environmental tradeoffs is important information in the discussion of policy issues. The economically preferred yardstick for measuring the effects of incentives and regulations for the Seymour Aquifer would be nitrogen percolation to groundwater. The stochastic nature of the losses and monitoring problems make the choice of this yardstick infeasible. However, with the development of sophisticated biophysical simulation models it is possible to construct a proxy for nitrogen discharge to the environment. Although such models are not perfect substitutes for actual monitoring, they serve as an alternative to actual pollution flows as a basis for applying policy tools.

With the 1995 Farm Bill and with the possible reauthorization of the Clean Water Act, Safe Drinking Water Act and Endangered Species Act, agricultural nonpoint pollution can be expected to be the focus of more attention in the future. As Congress and advocacy groups appear to be supporting stronger legislation relating to agricultural and water quality, and as states develop groundwater management policies, the estimated costs of various policy options for an watershed becomes important information for the successful design of cost effective policies.

Statement of Problem

Neilsen and Lee synthesized national data to identify regions of the country with a high potential for groundwater contamination from agricultural pesticides and fertilizer applications. Portions of the Texas Rolling Plains, which includes the Seymour Aquifer, are identified as having high potential for nitrate-nitrogen contamination. The area had been identified as containing elevated levels of nitrate in groundwater as early as 1948 (George and Hastings). The nitrate-nitrogen content of 62 water samples collected from the Seymour formation in 1962 varied from 5-41 ppm[1] (parts per million) with 39 exceeding the recommended Department of Health limit of 10 ppm (Ogilbee and Osborne). More recent studies (Kreitler; Harden and Associates; Aurelius) have shown that much of the water in the Seymour aquifer, the only source of groundwater in the area, is well above the EPA drinking water standard of 10 ppm. Besides nitrate, cases of pesticide contamination in selected water wells have also been identified in the area. Of the 63 Seymour aquifer wells sampled in Haskell and Knox Counties, water in 6 was found to contain pesticide residues (Aurelius). Many people in the Seymour aquifer region rely on private wells for their drinking water. These people have a higher risk of drinking contaminated water than those using public supplies because their wells are normally shallow and more susceptible to contamination.

As the most common contaminant of groundwater, nitrate is very mobile and does not absorb into aquifer material (Hendry). Treating groundwater contaminated with nitrate is technologically difficult and expensive. Growing evidence in the U.S. and abroad indicates a strong positive correlation between increase in nitrogen fertilizer use and nitrate level in shallow groundwater (Hallberg 1986; Schepers et al.). This raises questions about the fate and efficiency of nitrogen fertilizer use under current farming practices. Elevated nitrate levels in groundwater are attributed to the low relative cost of nitrogen and other chemical fertilizers and the ease with which nitrates move in soil. Research indicates that crops use only 50 to 70 percent of applied nitrogen fertilizer and the remainder is either transported by erosion or runoff, leached, or chemically transformed and lost to the atmosphere (Johnson; Keeny). Fertilizer use per acre harvested in the Great Plains has increased from about 27 lbs. in 1965 to nearly 80 lbs. in 1987 (Tweeten and Helmers; U.S. Department of Agriculture 1990).

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[1] Many regulatory standards are now expressed in terms of parts per million or parts per billion. One part per million means that there is one pound of a substance dissolved in a million pounds or 120,000 gallons of water.

While few cases of death or severe illness are linked directly to nitrate consumption, the human health consequences of nitrate-nitrogen exposure include methemoglobinemia (blue-baby disease) in infants[2] and gastric cancer in adults (Bouwer). Besides adverse health effects, there are other consequences of high nitrate level in water. In irrigation water, excess nitrogen may delay harvest and adversely affect the yield and quality of nitrogen-sensitive crops (FAO). Nitrate also encourages the growth of algae and other organisms which produce undesirable tastes and odors in drinking water. In addition, the potential for surface water pollution from groundwater is also an important environmental concern; approximately 30% of U.S. surface water stream flow is from groundwater sources (Saliba).

The problem of excessive nitrate in the Seymour aquifer area has been attributed to factors including natural soil nitrates (oxidation of atmospheric nitrogen from lightning and oxidation of organic soil nitrogen without cultivation), cultivation (oxidation of natural organic nitrogen in the soil due to plowing), human and animal wastes, inadequate well head protection measures, and fertilization used for agricultural production. Of approximately 274,500 acres comprising the Seymour aquifer, an estimated 265,000 acres or 97 percent are used for agricultural production (Texas Department of Water Resources).

Recent increases in the intensity of agricultural activities in some portions of the aquifer have raised new concern about water quality in the region. Intensification of crop production usually results in increased applications of nitrogen fertilizer. An additional concern for the area is that this increased crop acreage has been primarily associated with irrigated agriculture (Seymour Aquifer HUA Project Annual Report). Sandy soils along with the shallow depth to water (25-27 feet on average) create a potential for pollutants to leach into the aquifer. With nitrate concentrations already

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[2] Nitrate-nitrogen level greater than 10 ppm may expose infants to this disease.

above the established safe drinking water standard, even small increases in groundwater nitrate concentrations could make municipal and domestic water supplies unsafe.

Increasing state and federal attention to the existing water quality of the Seymour aquifer indicates the severity of the problem. The Texas State Soil and Water Conservation Board (TSSWCB) has designated the Seymour aquifer as a problem area with identified cases of pesticide contamination and excessive nitrate concentrations. The Soil Conservation Service (SCS), Texas Agricultural Extension Service, Texas State Soil and Water Conservation Board, and the Agricultural Stabilization and Conservation Service have entered into a joint project to study the Seymour aquifer, which has been designated as a Hydrologic Unit Area under the President's Water Quality Initiative. The objective of establishing this hydrologic unit is to accelerate the adoption of locally appropriate Best Management Practices to minimize agriculture's contribution to the pollution of the aquifer (Westmoreland). In an earlier, separate proposal that was later attached to the SCS proposal, the U.S. Geological Survey (USGS) identified the eastern part of the Gilliland/Truscott segment of the Seymour aquifer as the study area for a project.

Research Objectives

The objectives of this research are the following: (1) to evaluate the effects of various production practices on farmer's net income and water quality; (ii) to measure the sensitivity of various policy instruments on water quality and farmer's net income; and (iii) to compare the costs of these policies with the cost of bottled water for the region to have a relative measure of the externality.

Study Area

The Seymour Formation is situated between Wichita Falls and Lubbock in north-central Texas (Figure 1.1). It is approximately 60 miles north of Abilene and 75 miles southwest of Wichita Falls. The aquifer is composed of stream-deposited Pleistocene sands and gravels which have been dissected by Quaternary river valley erosion to form a series of discontinuous "plateaus" (Seymour Aquifer HUA Project Annual Report). These erosional remnants function as discontinuous, shallow, unconfined alluvial aquifers known collectively as the Seymour aquifer and serve as the main or sole source of water in the area. Though the exact number of aquifers comprising the unconnected Seymour Formation is difficult to determine, two are of particular interest: the segment underlying the communities of Gilliland and Truscott, and the bigger segment underlying Knox City, Haskell, Munday, and Goree.

This investigation is focused on the later segment which represents a single hydrologic unit of the Seymour aquifer covering approximately 274,500 acres or 430 square miles. The aquifer is the only source of fresh groundwater in the area and furnishes water for irrigation and municipal uses, with a minor amount used for manufacturing and livestock (Texas Water Commission). There are over 2,000 irrigation wells and the typical well yield is 300-400 gpm (gallons per minute). The aquifer is generally composed of discontinuous beds of poorly sorted gravel, conglomerate, sand, silty clay and caliche (Price). Saturated water of the aquifer varies widely, but the total thickness is usually less than 100 feet (Texas Department of Water Resources). Wide variations exist in the depth to groundwater throughout the aquifer. The average depth to water is 23 feet, but ranges from 4 to 55 feet. The average concentration of nitrate in the aquifer is slightly above the EPA standard of 10 ppm, but in some areas the concentration is as high as 50 ppm.

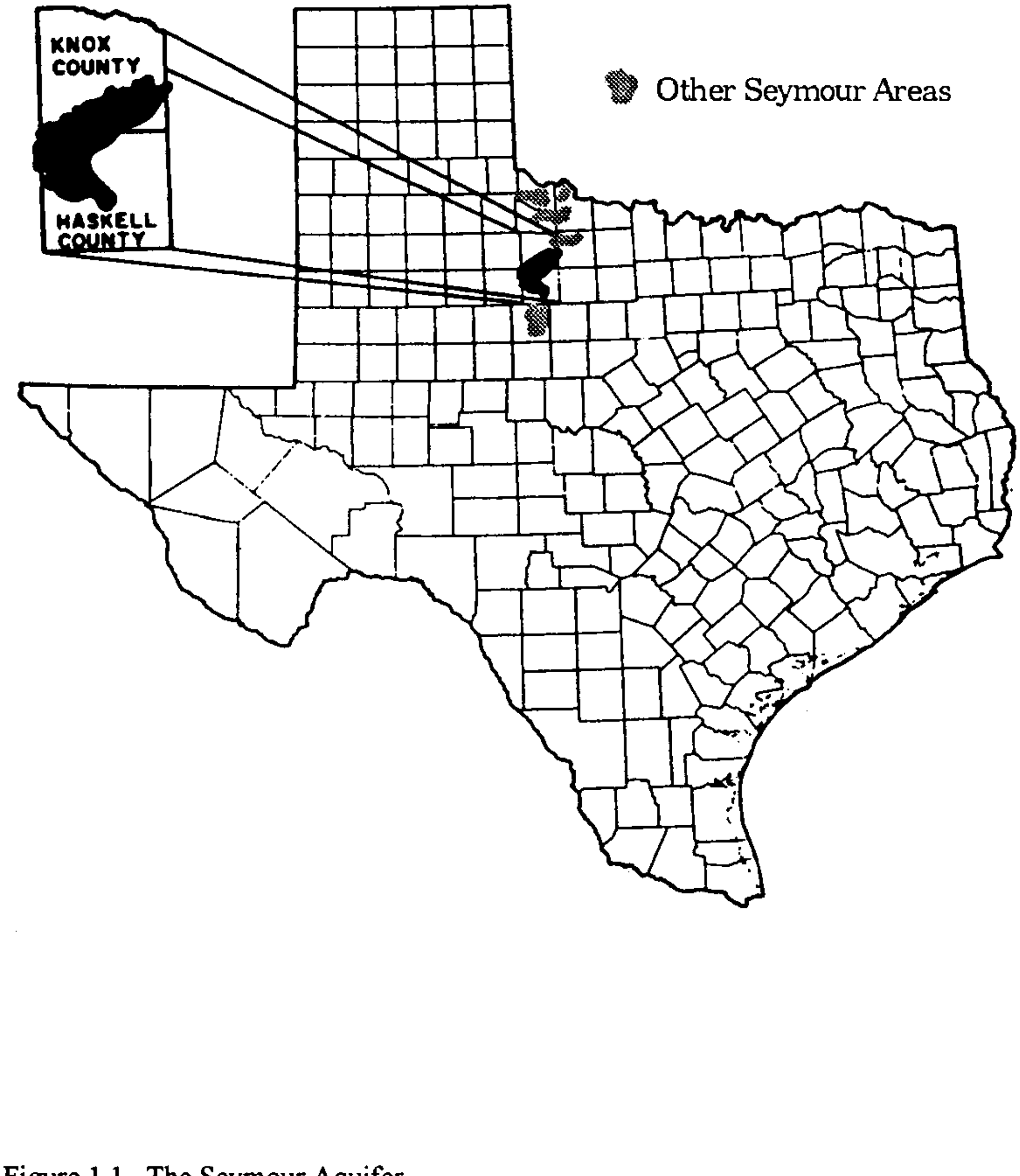

Figure 1.1. The Seymour Aquifer
Source: Harden and Associates

The major crops in the area are cotton (both irrigated and dryland), dryland wheat, sorghum (dryland and irrigated), and irrigated peanuts. Wheat and cotton account for 85% of the total acres used for agricultural production (Seymour Aquifer Hydrologic Unit Project Annual Report). This study was directed to irrigated and dryland cotton, and dryland wheat.

The soils in the area are Abilene and Miles-Rotan (Soil Survey of Haskell County, Texas; Soil Survey of Knox County, Texas). These soils are deep, nearly level (slopes are mostly less than 1 percent), loamy soils formed in old alluvium. Previous studies on Knox County (Onken et al. 1977; Onken et al. 1979; Wendt et al.) focused on the Miles fine sandy loam soil (Udic Paleustalfs).

The dominant source of recharge to the Seymour aquifer is through direct soil infiltration of rainfall and irrigation water. The majority of this recharge occurs near Rochester - the southwest portion of the aquifer (northwest quarter of Haskell County and southern third of Knox County) which is characterized by deep, sandy soils. The Brazos River and Lake Creek are the primary surface streams joining the Seymour, but both occur at elevations below the water table and thus do not contribute to aquifer recharge. Groundwater movement is generally from higher-elevation recharge areas to lower-elevation discharge areas or towards areas of man-induced discharge created by pumping large capacity wells (Texas Water Commission).

The region has a warm-temperate, subtropical climate with dry winters and hot summers. Tropical air has a dominant effect on area weather from April through October, while air masses of polar origin are most significant from November through March. The average annual precipitation is 24.9 inches, with about 75% occurring from April through October. The heaviest rainfall occurs typically in May and October. The average daily maximum temperature in July is 97.7 degree F and the average frost-free period is 219 days.

Review of Selected Literature

The research reported here builds upon the conceptual and empirical approaches found in some existing studies to develop a bioeconomic analysis of agricultural groundwater pollution. The theoretical aspects of nonpoint pollution are developed in Langham, Sharp and Bromley, Griffin and Bromley, Saliba, Shortle and Dunn, Milon, Segerson, Wetzstein and Centner, and Zeitouni. The empirical literature on economic and policy issues related to agricultural nonpoint-source pollution is extensive. Because of the complex linkages between the physical and economic environment, empirical studies are increasingly relying on biophysical models. Early examples of bioeconomic integration are presented in Jacobs and Timmons, Jacobs and Casler, Park and Shabman, and Heimlich and Ogg. They have been followed by Christensen; Anderson, Opaluch, and Sullivan; Setia and Magleby; Gardner and Young; Lee et al.; Dillon, Mjelde, and McCarl; Braden, Hericks, and Larson; Bouzaher, Braden, and Johnson; and Bryant et al. These studies illustrate the reliance that is being placed on biophysical aspects in conjunction with economics. The following is a brief overview of related studies dealing specifically with integrating process models and economic analysis.

By integrating plant simulation, hydrologic, and economic models, Johnson, Adams, and Perry evaluated on-farm costs of strategies to reduce nitrate groundwater pollution in the Columbia Basin of Oregon. Results suggest that changes in timing and application rates of nitrogen and water reduce nitrate pollution with little loss in profits. Once such practices are adopted, further reductions in nitrates can be achieved only at increasing costs to producers.

Mapp et al. developed a regional programming model linked with crop yield-chemical movement (EPIC-PST) and aquifer (MODFLOW) models to evaluate the potential impacts of various water quality policy alternatives for the Central High Plains region. The analysis includes a baseline showing the current production situation and expected future conditions, and three water quality protection policies: restrictions on the total quantity of nitrogen applied, restrictions on per acre nitrogen applications, and limitations on the availability of selected pesticides which have been identified as likely to leach through the plant root zone. Runoff and percolation of nutrients and pesticides, irrigation water pumped, production, and net income associated with the baseline and alternative water quality policies were evaluated.

Taylor, Adams, and Miller examined economic incentives and other mechanisms to offset nonpoint-source pollution from agriculture. The authors linked EPIC to linear programming models for case farms in the Willamette Valley of Oregon. The results indicate that site-specific resource conditions and production possibilities greatly influence policy effectiveness and the cost of achieving pollution abatement.

Carriker attempted to estimate the economic and environmental tradeoffs from managing nitrogen fertilizer in Great Plains corn production. Using the CERES-Maize corn growth simulation model, corn yields and a mass-balance approximation of environmental loading of nitrates were employed in the evaluation of net return risk under several economic incentive scenarios to reduce nitrate pollution. Results suggest that more risk averse farmers were likely to better manage nitrogen in response to economic incentives to reduce nonpoint-source contaminants.

Sabbagh et al. used the EPIC-PST model to simulate simultaneously the effect of different agricultural management practices on crop yields and pesticide losses by surface runoff, sediment movement, and leaching under irrigation. Their simulation results indicated that surface irrigation could result in larger leaching of chemicals than sprinkler irrigation. Results suggest that there are tradeoffs between environmental and economic benefits, and the reduction of chemical losses is possible only with lower profits.

Conner and Smida used the CERES plant simulation model along with a multi-objective programming model to explicitly identify how alternative agricultural pollution abatement policies involve trading competing environmental objectives against one another. The results indicate that in a surface irrigated agricultural settings with limited financial resources, incremental reductions of nitrate leaching beyond a certain threshold may have a high opportunity cost in terms of sediment loss.

Young and Crowder linked the CREAMS (Chemical Runoff and Erosion from Agricultural Management Systems) simulation model to a linear optimization model to estimate income nutrient loss tradeoffs. Their results show that if water quality concerns are primarily for surface water, locally appropriate best management practices can significantly reduce nutrient runoff and soil erosion with little effect on farmer net returns.

Diebel et al. used CREAMS and GLEAMS and a 15-year mathematical programming model to evaluate the effectiveness of low-input agriculture under alternative policy scenarios, as a strategy to protect ground water quality in Richmond County, Virginia. The study suggests that a potential exists for chemical and nutrient leaching even with low-input agricultural activities. Nitrogen percolation control appeared to pose an even greater challenge to farmers than percolation of pesticides.

Two recent Indiana studies used biophysical simulation models and economic analysis to investigate the relationship between farming systems and water quality. Foltz et al. used two process models (EPIC-WQ and GLEAMS) and linked them with a farm-level linear programming model to assess the economic and environmental implications of selected eastern Corn Belt farming systems. The results showed the sensitivity of production practices on net returns and atrazine and alachlor runoff and nitrate percolation. Mainali used EPIC-WQ and a farm-level mathematical programming model to evaluate atrazine runoff and profit for the White River region in Indiana. The study analyzed relative impacts of alternative policies for controlling environmental flows and their effect on farm net returns.

Using a mathematical programming model, Kramer et al. analyzed the effects of alternative policy scenarios on farm income, production levels, nitrogen and pesticide runoffs and soil erosion in two Virginia watersheds. Their results indicate that depending on the pollutant involved, there can be different environmental effects due to a regulatory policy. They also revealed that effluent tax and regulatory approaches can impose a large financial burden on the farmers.

A limitation of these studies is that all impacts on groundwater quality were not included directly. For example, the studies dealt with percolation below the crop root zone. A more realistic approach would be to consider leaching of nitrate through the non-saturated zone into the aquifer. Although these aspects often involve interdisciplinary efforts, biophysical simulation models are interdisciplinary and studies using these models must be ready to investigate these aspects to be more realistic. Most studies focused on the loading of pollutants instead of the concentration on which the federal standard is based. Studies that focused on concentration (Mainali, for example), ignored other important aspects such as government farm programs.

A related literature has emerged which dealt with the theoretical and empirical issues of averting expenditures (Courant and Porter; Watson and Jaksch; Harrington and Portney; Bartik; Roach; Spofford, Krupnick, and Wood; Smith and DesVousges; Harrington, Krupnick and Spofford; Abdallah 1989, 1992). The literature argues that 'cost of avoidance' expenditures are biased and overstates willingness-to-pay (WTP). The present study also compares the cost of policies in terms of farmer's loss of profit with the cost of bottled water to have a partial or approximate measure of the next best alternative for potable water in the region.

CHAPTER II

THEORETICAL BASIS

The conceptual framework used in this study is based on the theoretical foundations of externality theory and the expected utility literature. The problem of externalities and the associated market failure had long been a part of microeconomic theory. The theoretical results regarding the choice among the key policy instruments for the control of externalities were developed in the late 1960s and 1970s. Economists saw pollution as the consequence of an absence of prices for certain scarce environmental resources (such as clean air and water) and they prescribed the introduction of surrogate prices in the form of unit taxes or "effluent fee" to provide the needed signals to economize on the use of these resources.

The expected value-variance framework evolved with the work of Tobin and Markowitz where they showed that an expected utility ranking of a random variable can be represented by their mean and variance. In the absence of a superior criterion, the E-V criterion has still been used in agricultural economics, despite some of its limitations.

Externality and Market Failure

The theoretical basis for evaluating groundwater contamination and policy options to address the issue is founded on the concept of externalities. The activities of one economic agent (farmers, for example) can affect the consumption set, or preferences of another (consumers of drinking water) which is not reflected in market prices. The mainstream literature defines externality as an interdependence among economic actors for which a market or some other compensatory device does not exist (Baumol and

Oates; Bromley; Heller and Starrett). This definition emphasizes market absence as a necessary condition for an externality. Griffin provides an institutionally unbiased definition of externality where he defines externality as an interdependence among people. This interdependence can be between consumers and producers, between consumers, or between producers.

The three most important dichotomies in the externality literature are the Pareto relevant vs. Pareto irrelevant externality, undepletable vs. depletable externality, and pecuniary vs. technological externality. Pareto relevant and Pareto irrelevant externalities are illustrated in Figure 2.1, Panel (b). The level of a polluter's activity, Q, is shown on the horizontal axis. Costs and benefits in monetary terms, are shown on the vertical axis. MNPB is "marginal net private benefits" derived from panel (a). It shows a demand and marginal cost curve for a perfectly competitive firm. By subtracting marginal cost (MC) from price (P), we derive a marginal profit curve (M_π). M_π shows the extra profit made by expanding output by one unit. Clearly, total profits, the area under M_π, are maximized when $M_\pi = 0$. Profit is equivalent to the net benefit obtained by the firm. Hence, marginal profit is formally equivalent to marginal net private benefits. MEC (in panel (b)) is the "marginal external cost" i.e. the value of the extra damage done by pollution arising from the activity measured by Q. It is shown here as rising with output.

If society's goal is to maximize the sum of benefits minus the sum of costs, then the area A is the largest area of net benefit obtainable. Q^* is the optimal level of activity and area B is the optimal amount of economic damage. Q^* is termed as Pareto irrelevant externality because this level of externality corresponds to the largest net benefit and there is no need to remove it. Externality level Q_π is said to be Pareto relevant because its removal leads to a "Pareto improvement" i.e. a net gain in social benefits.

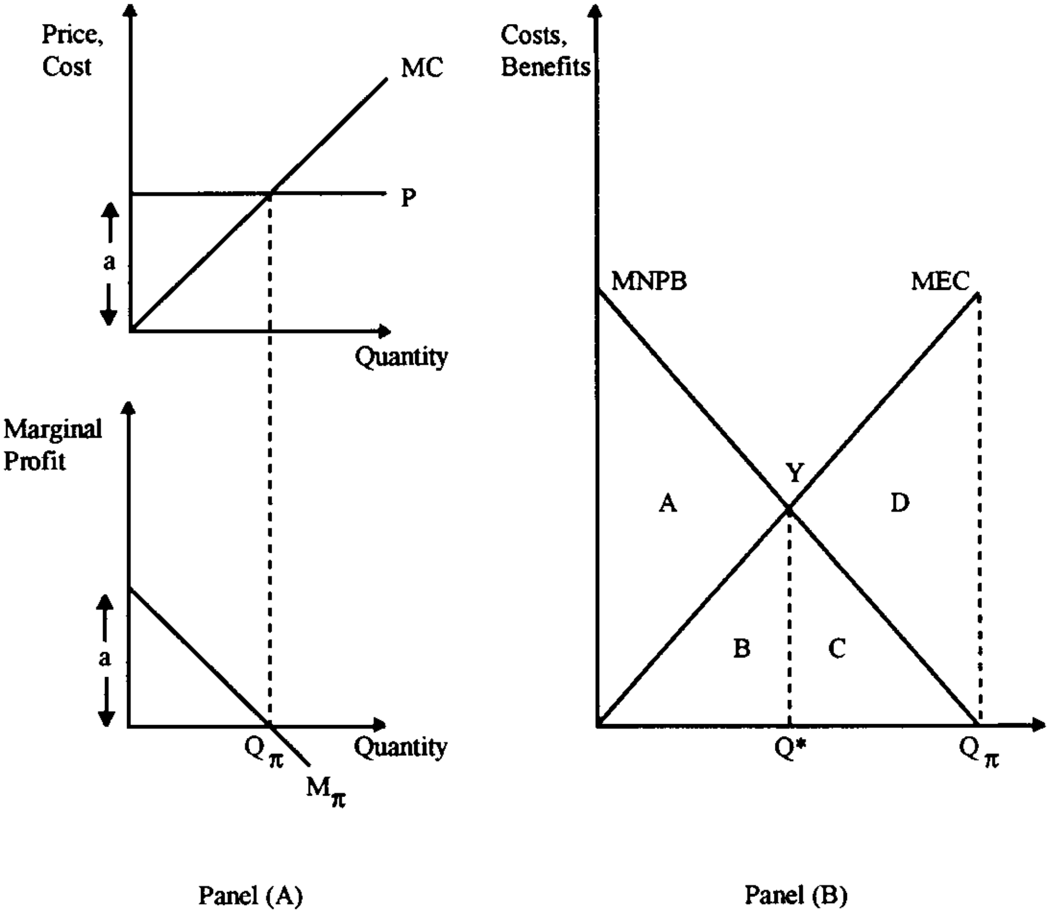

Figure 2.1. Pareto Relevant and Pareto Irrelevant Externality
Source: Pearce and Turner

The other two dichotomies in the literature are the depletable vs. undepletable externality and pecuniary vs. technological externality. An undepletable externality is one where the greater or lesser impact on one person does not decrease or increase the impact on others. A greater consumption of drinking water with high nitrate concentration by one person will not decrease the nitrate exposure of another person exposed to the same risk. In this case, it is an undepletable externality. With an depletable externality, greater or lesser impact on one individual decreases or increases the impact on others. With pecuniary externality, interdependence is transmitted by a price variable (pecuniary externality is Pareto irrelevant) while a technological externality is transmitted by a quantity variable (interdependence is in terms of real quantities).

The Resolution of Externalities

Policies Directed Towards the Restoration of Markets

Although the absence of externalities is one of the conditions required so that competitive markets will achieve an efficient resource allocation, this does not mean that the resolution of an externality must be done with government intervention.[3] An externality situation can be resolved by changing the structure of entitlements: property rules, liability rules, and inalienable entitlements. "Property rules are fundamental to the operation of markets which assign value prior to an interdependence, and liability rules necessitate some form of judicial system to settle value after an interdependence has occurred. However, sufficiently established liability rules may also provide a basis for market transactions. Inalienable entitlements act as constraints on economic activity, presumably to advance higher-order social objectives" (Griffin, p.602).

It has been reported in the literature that given competitive conditions and zero transactions costs, efficiency will be achieved so long as the structure of rights is non-attenuated, i.e., universal, exclusive, transferable, and enforced (Cheung). For the Seymour aquifer area, the economic problem relates to contamination of groundwater rather than allocation and thus establishment of groundwater rights may not resolve the problem of nitrates.

The imposition of liability rules effectively places an "expected price" on polluting activities. However, like property rules, there are some problems which may impede the success of liability rules in Seymour aquifer. Liability rules rely on a case-by-case

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[3] The term government can range in meaning from the local, state or regional government to the various branches of the federal government.

determination based on the unique circumstances for each case. Unlike a tax, it provides compensation to victims which can result in inefficient levels of defensive activities (Baumol and Oates, p.23). The actual 'price' paid by the source may be much less than actual damages because of imperfections in the legal system. Often it is difficult to impose liability on responsible parties resulting from uncertainty over causation, statutes of limitation, or high costs of prosecution. Bankruptcy has been used as a means of avoiding large payments for damages.

One of the greatest defenses of non-intervention is Coase's argument that in the absence of transactions costs and strategic behavior, the distortions associated with externalities will be resolved through voluntary bargains struck among the interested parties regardless of the initial assignment of property rights. First, this is usually the case when there are a small number of agents involved and the costs of negotiation between them are relatively low, although this is not always the case. Most cases of air or water pollution such as Seymour aquifer, involve a large number of polluting agents and transactions costs are typically too large to permit a Coasian resolution. Second, the achieved quantity of abatement of an external diseconomy will be greater under a specification of property rights that protects the affected party and less under one that protects the acting parties. Third, there is the difficulty of identifying bargaining parties. Some groups of present generation may have to bargain for the future generation. Sufferers may be unaware of the source of pollution from which they suffer. Fourth, there is the problem of threat making: if a sufferer pays a polluter, then other polluters may come in and demand compensation.

The Choice of Policy Tools

Because of the difficulties of non-intervention policies, parallel research approaches have been developed to investigate situations where direct government intervention is needed to remedy externality problems. The seminal work, *The Theory of Environmental Policy*, by Baumol and Oates was the driving force behind using a general equilibrium framework to generalize externality analysis. The theoretical results of Baumol and Oates are the following:

"Irrespective of whether the externality is of depletable (private-goods type) or undepletable (public-good type) variety, the proper corrective device is a Pigouvian tax (or subsidy) equal to marginal social damage levied on the generator of the externality with no supplementary incentives for victims (so long as the number of victims is large). This fiscal instrument is needed because no normal market price can fulfill this asymmetry requirement." (p. 23). A tax on the victims is needed in two cases:

(i) "In the small number case where there are incentives for strategic behavior, a tax on victims that accompanies a Pigouvian tax on generators may make sense, at least in theory." (p.35).

(ii) "In the special case of a shiftable externality, victims must themselves be subject to a tax equal to the marginal social damages caused by their shifting activities. Only if the person happens to be both victim and generator of externalities simultaneously should he or she be subject to a tax, but only for assuming the latter role." (p. 26).

The mechanism of a Pigouvian tax is depicted in Figure 2.2. It represents a situation where the supplier of a good does not bear all the costs of producing the good, or where the marginal private cost (MPC) is less than the marginal social cost (MSC) of the good. This can happen when property rights are not assigned or transaction costs inhibit negotiation between the supplier and demander. In this externality situation, the producer of the good produces more than is socially optimal ($Q^0 > Q^*$). This misallocation of resources (market failure) results in a loss of welfare measured by area abc in Figure 2.2. A solution to this problem is to induce the producer to supply the socially optimal amount of the good by imposing a Pigouvian tax on each unit of production such that the private marginal cost is increased to the point where it equals the marginal social cost of the production of the good. The same objective can also be achieved by subsidizing the producer so that his private marginal cost is reduced to the point where he is willing to supply the socially optimal amount of the good. Theoretically, a subsidy of 50 cents per ppm of nitrate percolation averted creates the same opportunity cost for nitrate percolation as a tax of 50 cents per ppm of nitrate percolation. The regulator can use either the stick or the carrot to create the desired incentive for abatement efforts.

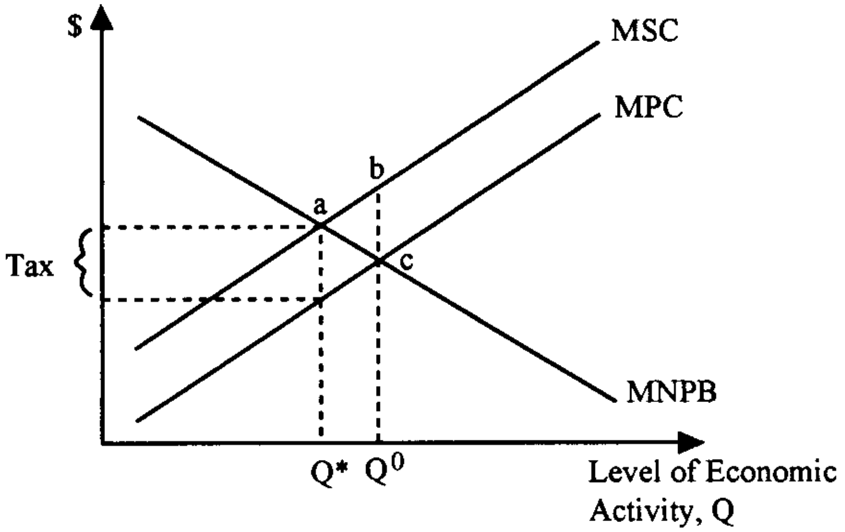

Figure 2.2. The Mechanism of a Pigouvian Tax

Because of the problem with measuring marginal externality cost, Baumol and Oats suggested instead a second best solution where the policy maker can set some aggregate environmental target and then the least-cost policy (for example, a charge/fee) can be implemented to reach the target. An effluent tax, or more appropriately a *leachate tax* (Johnson, Adams and Perry), is a tax imposed on the actual level of effluent per unit. The total payment could be found by multiplying the fee times the amount of pollution emitted. In Figure 2.3, a hypothetical illustration of emissions charge is presented. If the firm were to decide against controlling any emissions, it would have to pay T times 10, represented by area OTBC. But the firm would minimize its cost by choosing to clean up 6 units of pollution and emitting 4 units. At this allocation the firm would pay control costs equal to area OAD and total emission charge payments equal to area ABCD for a total cost of OABC. This is clearly less than OTBC, the amount the firm would pay if it chose not to clean up any pollution.

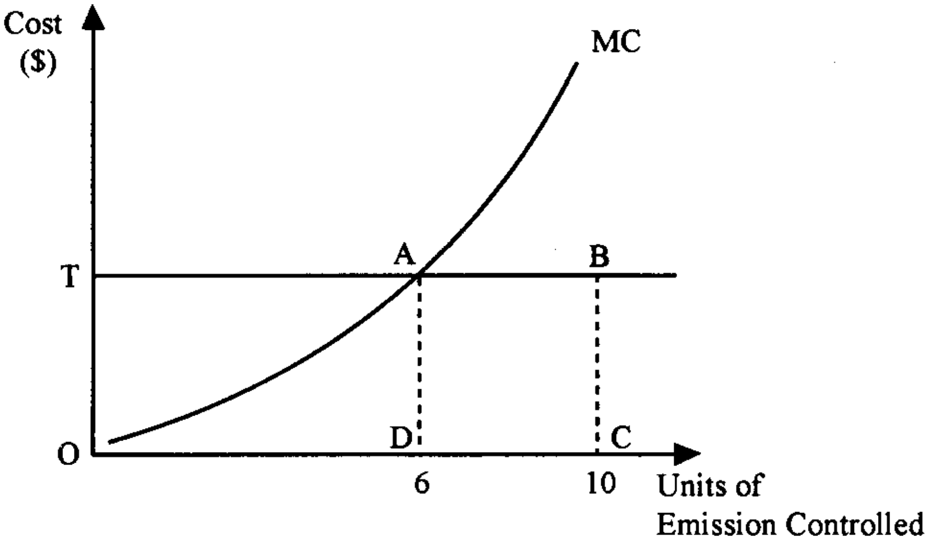

Figure 2.3. Illustration of an Emissions Charge

An emissions tax or emissions reduction subsidy has several attractive features. With such a policy, the minimum cost allocation of meeting a predetermined emission reduction can be found by a control authority, even when it has no information on control cost. The polluter pays the tax on the amount of pollution discharged or receives subsidy on the pollution not discharged, and hence has a continuing incentive to search for pollution reducing technologies. Its effectiveness does not depend on the development of a smoothly functioning market (necessary for permits). It is also a source of revenue for the regulatory authority which can use the fund to reduce other taxes or for developing best management practices that are environmentally sound and maintain economic viability of the farm.

Emissions taxes and subsidies for emissions reduction have limited practical value in agriculture because of the costs required to monitor actual pollution rates for each farm (Segerson). It imposes added farm management costs related to basing input decisions on complex pollution forecasting models (Shortle and Dunn). However, analysis of an emission tax and subsidy is useful for forming socially optimal pollution goals and in generating fertilization strategies, assuming the tax (or subsidy) levels roughly approximate the true marginal social cost of nitrate pollution.

From a distributional perspective there are some important asymmetries between Pigouvian taxes and subsidies. Subsidies increase profits, while taxes decrease them. Unlike efficiency point of view where the two policies are alike, the policy instruments have quite different distributional implications when the long-run, entry-exit decisions of firms are considered.

An input tax is another policy option for addressing agricultural nonpoint pollution, i. e., discourage high use of inputs that contribute to pollution. Because of the revenue generating ability along with the relatively low cost of implementation, input taxes (mostly on fertilizers), have been used in several states in the U. S. The overall purpose of nitrogen tax in these states is not so much to change producer behavior through higher fertilizer prices as to generate revenue that is used to nitrogen reduction research and education programs (Carlin). From a theoretical standpoint, an input tax should differ for each farm and be placed on a broad base of inputs that influence discharge. However, a regulatory agency often resort to a uniform tax on one input that is most closely related to the pollution problem and can be easily monitored. The loss of producer income under such a scheme would be substantial as a farmer would be forced to make huge adjustments in terms of one input only (fertilizers, for example).

Regulations are another common policy instruments for addressing pollution issues in addition to taxes and subsidies. Instead of specifying economic incentives and allowing economic agents to choose corresponding production and consumption levels, the government can specify these quantities directly. Regulations can also induce Pareto optimality if they are appropriately chosen. Optimal regulations and optimal economic incentives are related as duals. As indicated by Baumol and Oates and others, regulation can be advantageous relative to incentives when the issue contains stochastic elements (such as weather patterns). In the area of nonpoint pollution, two types of regulations are applicable: performance standards (regulation that targets actual emission level), and design or technology standards (regulation placed on production technology).

A performance standard places limits on the emission of nonpoint pollutants without putting any restriction on production technology. Performance standards are ranked highly with respect to least-cost control because they are based on actual pollutant discharges and farmers have an incentive to use their specialized information to minimize costs. Polluters can also continuously search for lower cost technologies for reducing pollution. This study, which is based on a case farm, assumes that all farms are homogeneous. Thus, performance standards in this study do not have any efficiency advantage over regulatory policies. Although there are some problems with measuring and monitoring nonpoint source pollution, estimates obtained from biophysical simulation models can be used as a measure of performance. The model solution under a performance standard also provides an estimate of the applicable design standards.

Design standards specify what actions must or must not be taken by landowners. An example would be the specification of management practices that must be used by the farmer. Compared to performance standards, design standards are easier to enforce. However, the disadvantage is that these programs often result in across-the-board requirements for control measures that fail to take account of the particular circumstances of individual polluters. Also, there is a lack of compelling incentives for research and development in abatement technology.

Often it is crucial to prevent levels of pollution from exceeding certain damaging threshold levels. Marketable permits are especially attractive in these situations because of the direct control it provides over levels of emissions through limiting the number of permits. Since in most cases, polluters have different marginal costs of abatement, opportunities for trade exists - low cost polluters selling permits and high cost polluters buying them. The scheme is economically efficient since the price of permits will approximate the marginal external cost. Moreover, if the environmental authority decides to keep the same level of pollution, the new entries in the market will raise the price of permits and the overall cost minimization properties of the system will be maintained. There is also opportunities for non-polluters - an environmental pressure group like the Sierra Club can enter the market and buy permits.

Although the idea of marketable permits is becoming increasingly popular in the United States, the actual experience with marketable permits, especially in nonpoint pollution, is limited. Search costs, strategic behavior and market imperfections can impede the working of pollution permits. In most nonpoint pollution cases, it is generally either technically infeasible or very expensive to measure the emissions of individual producers. Furthermore, for a region such as Seymour aquifer, marketable permits may not be an appropriate policy tool because of the absence of high and low polluting farmers with different management practices.

With the help of a biophysical simulation model, the effect of these polices (performance and design standard, performance tax and performance subsidy, and input tax and input subsidy) on producer income is estimated and reported in Chapter V.

Expected Utility and Expected Value-Variance Analysis

Risk-averse behavior in farm planning models, particularly as related to the adoption of different production practices has been shown to be important. To address risk at the farm level, several techniques for incorporating risk behavior have been developed in recent years. Two different approaches to represent an agent's preferences over strategies yielding random payoffs are in wide use: expected utility (EU) and expected value-variance (EV)[4] approach. Maximizing expected utility is the predominant theoretical foundation for risk analysis. This concept asserts that a particular alternative is preferred to another as long as the expected utility is greater. Thus, the best or optimal solution to a particular problem would be one with the maximum expected utility. Under the expected value-variance (EV) approach, the agent is assumed to rank the alternatives according to the value of some function defined over the first two moments of the random payoff (mean and variance). This approach is founded on the empirically tested proposition that farmers (who are typically risk averse) often prefer farm plans that provide a satisfactory level of security even if this means sacrificing income on average (Binswanger; Dillon and Scandizzo; Lin, Dean, and Moore).

The expected value-variance criterion of quadratic programming assumes that the iso-utility curves will be convex when plotted in E-V space (Figure 2.4) or that the farmer is a risk averter. That is, along every iso-utility curve the farmer would prefer a plan with higher variance only if the expected value were also greater (i.e. $\partial E/ \partial V > 0$), and this compensation must increase at an increasing rate with increases in variance (i.e., $\partial E^2 / \partial V^2 > 0$). The farmer should then rationally restrict his/her choice to those farm plans for which the associated income variances are minimum for given expected income levels. The problem facing the farm analyst is to develop the set of feasible farm plans

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[4] Also known as expected value-standard deviation (ES) or mean-standard deviation (MS).

having the property that variance is minimum for associated expected income level. Such plans are called efficient E-V pairs and they define an efficient boundary over the set of all feasible farm plans (segment OQ in Figure 2.4)

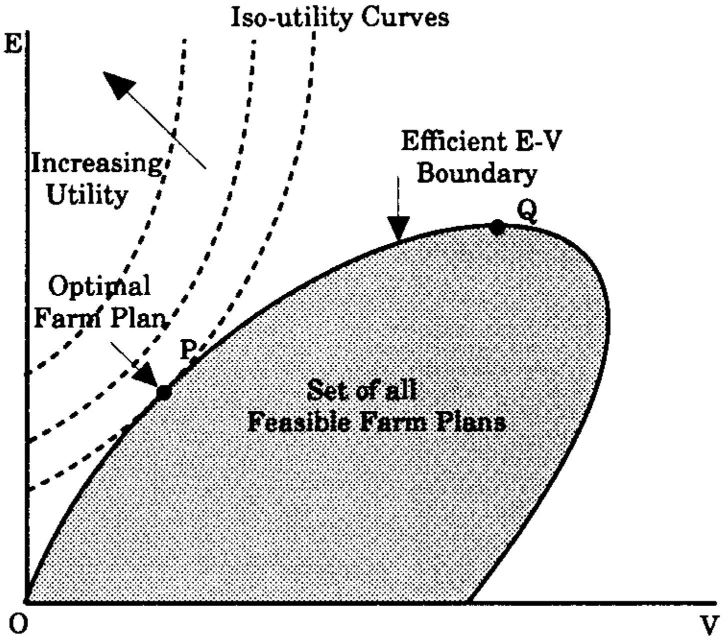

Figure 2.4. The Optimal E-V Farm Plan
Source: Hazell and Norton

Given a set of efficient farm plans, the acceptability of any particular plan to an individual farmer will depend on his preferences among various expected income and associated variance levels as described by his E-V utility function. When this function can be measured, a unique farm plan can be identified which offers the farmer highest utility. This is the efficient farm plan P in Figure 2.4.

The pioneering work of Tobin (1958a) and Markowitz showed that an expected utility (EU) ranking of a set of random variables can be represented by their mean and standard deviation. Since then, a considerable literature has emerged which discusses the restrictions that must be placed if consistency between an EU and EV ranking of those alternatives is to be ensured. Borch (1969) and Feldstein separately criticized the widely used mean-variance analysis of portfolio selection. Borch contended that any system of upward sloping mean-standard deviation indifference curves can be shown to be inconsistent with the basic axiom of choice under uncertainty. Feldstein, by using a log-utility function and a log-normal distribution for investment outcome has shown that EV indifference curves for a risk-averter need not be convex downwards, though upward sloping.

These criticisms forced Tobin (1969) to acknowledge that it is applicable only if either the investor's utility function is quadratic, or if the uncertain outcomes are normally distributed. Either of these two conditions, by itself, is sufficient for this consistency. Since the work of Tobin and Markowitz, much research effort has been devoted to examining the extent to which either of these two conditions can reasonably be assumed to hold. The quadratic utility function has been criticized by Arrow and Hicks because of its highly implausible implication of increasing absolute risk-aversion. On the other hand, the assumption of normal distribution for all outcomes of risky investments had also been questioned. Inspite of these criticisms, EV analysis has continued to be used in agriculture mainly because of two reasons.

First, other alternative methods did not prove to be absolutely superior. One alternative approach used is the direct expected utility maximization based on empirically observed distributions (Lambert and McCarl). One desirable property of this approach is that, unlike EV analysis, it does not assume normality of distribution of returns. However, to get a good approximation of the distributions, many states of nature (points with positive probabilities) are needed. The utility function for an empirically observed distribution is also not known. Furthermore, it does not eliminate the need to assume that the sample data provide an adequate representation of the distribution of the parent population.

Second, a large number of studies showed that there is theoretical and empirical justification for the use of EV analysis beyond the above mentioned two cases to which Tobin intended to confine its application. The motive was to show that some conditions are likely to exist which is both sufficient to ensure consistency between the EU and EV approaches and is theoretically supportable and empirically verifiable in at least some common economic models (Tsiang 1972, 1974; Hawawini; Levy and Markowitz). Samuelson (1967, 1970) have argued that the mean-variance analysis may be viewed as an approximation to a more general choice model. Tsiang (1972, 1974) showed that the EV analysis can be justified as a useful approximate method for portfolio selection even when the utility function is not quadratic nor are the distributions of returns always normal. The only condition required is that risk assumed by the investor must remain a fairly small fraction of his/her total wealth, including not only his/her entire net worth but also his/her human capital. Tsiang showed that acceptable utility functions, which are nonpolynomials, can generally be expanded into Taylor series provided that they are continuous and have derivatives. If the convergence of the series is sufficiently fast, so that for fairly close approximation the terms beyond the second moments can be neglected, then the expected utility can be approximated by the first two moments (mean and variance) even if the utility function is not quadratic and the uncertain outcomes not normally distributed.

The appropriateness of such an approximation has been debated in the literature (Borch 1974; Bierwag; Levy; Tsiang 1974). The critics of the E-V model basically used Gamma, Cauchy, and Bernoulli distributions to demonstrate the limitation of the E-V model. According to Tsiang, the EV analysis is not meant to be a universally valid mathematical theorem on preference ordering of all stochastic variables, or one that may be regarded as conclusively disproved by a single counterexample. It is meant only to be a practical method of portfolio analysis for investors who regularly take rather small risks relative to their total wealth. This condition is more likely to be met in U.S. agriculture compared to subsistence farms in developing countries (Hazell). In addition, usually, as in so many problems of applied statistics, ordinarily the investor does not know the exact shapes of the distribution functions of investment returns. One has only some estimates of the locations, dispersions and perhaps some vague idea of the degrees of skewness of the distributions to work on. These facts, according to Tsiang, constitute the basic rationale of the mean-variance analysis. Hawawini defended the E-V analysis by showing that farmer's behavior under uncertainty can be easily derived using a geometric approach based on the mean-standard deviation framework. In an empirical analysis, Levy and Markowitz examined some empirical relationships between EU and their approximation function for various utility functions and empirical distributions. Their results showed that the approximation is close enough if the distribution of returns is not too speculative in nature.

According to Hazell and Norton, since farm income is often an aggregate of many independent sources of revenue and cost risks, by the Central Limit Theorem, it should be approximately normally distributed. In many cases it is not possible to reject this hypothesis given the length of time series data available on farm incomes. Hazell and Norton also observes that the computational advantages of the E-V model must be offset against its theoretical limitations (if any). It can be solved by quadratic programming or by linear programming approximation. Utility functions with preferred theoretical properties often have expected values that are difficult to evaluate numerically and higher order polynomials that might be used to approximate more desirable functions can lead to nonconvex programming problems.

Meyer provided another condition which, if satisfied, implies that an agent's EU ranking of a set of random variables could be represented by a ranking based only on their mean and standard deviation. Known as the location and scale (LS) condition, it requires that the random variables comprising the choice set be represented by distribution functions which are obtainable from one another by a shifting and/or rescaling process. Symmetry, infinite tails, a single mode, and many other characteristics of the normal, which the data set may not satisfy, are no longer required.

CHAPTER III

APPROACH AND PROCEDURES

A unique characteristic of agricultural resource problems is the close linkages with the physical and biological sciences. With society's increasing demand for a cleaner environment along with the traditional demands for increased productivity, a multidisciplinary research effort to address these issues is required. For example, nitrate leaching is affected by the type of crops produced (extent of crop uptake of nitrogen and nitrogen fixation) and the management practices. The impact of management practices on groundwater quality can be dramatically impacted by (i) weather, (ii) porosity and layering within the soil profile, (iii) depth of the material that lie between the top soil and the groundwater surface (known as the dewatered or vadose zone), and (iv) occurrence of denitrification which releases nitrates from soil into the air (Taylor et al.). Capturing this total biophysical process is essential for an economic analysis of agriculture's impact on groundwater quality.

The general methodology framework of this research involves the following: (i) validation of a process model (EPIC-WQ - Erosion Productivity Impact Calculator - Water Quality) for the study area; (ii) estimation of regression equations using simulated crop yield and nitrogen percolation for various input combinations over a simulated twenty five years; (iii) development of a risk sensitive farm-level optimization model utilizing the results from the process model and the response functions; and (iv) the evaluation of implications of alternative policies on farm profit and groundwater quality. Figure 3.1 is a flow diagram depicting the general methodology used in this research.

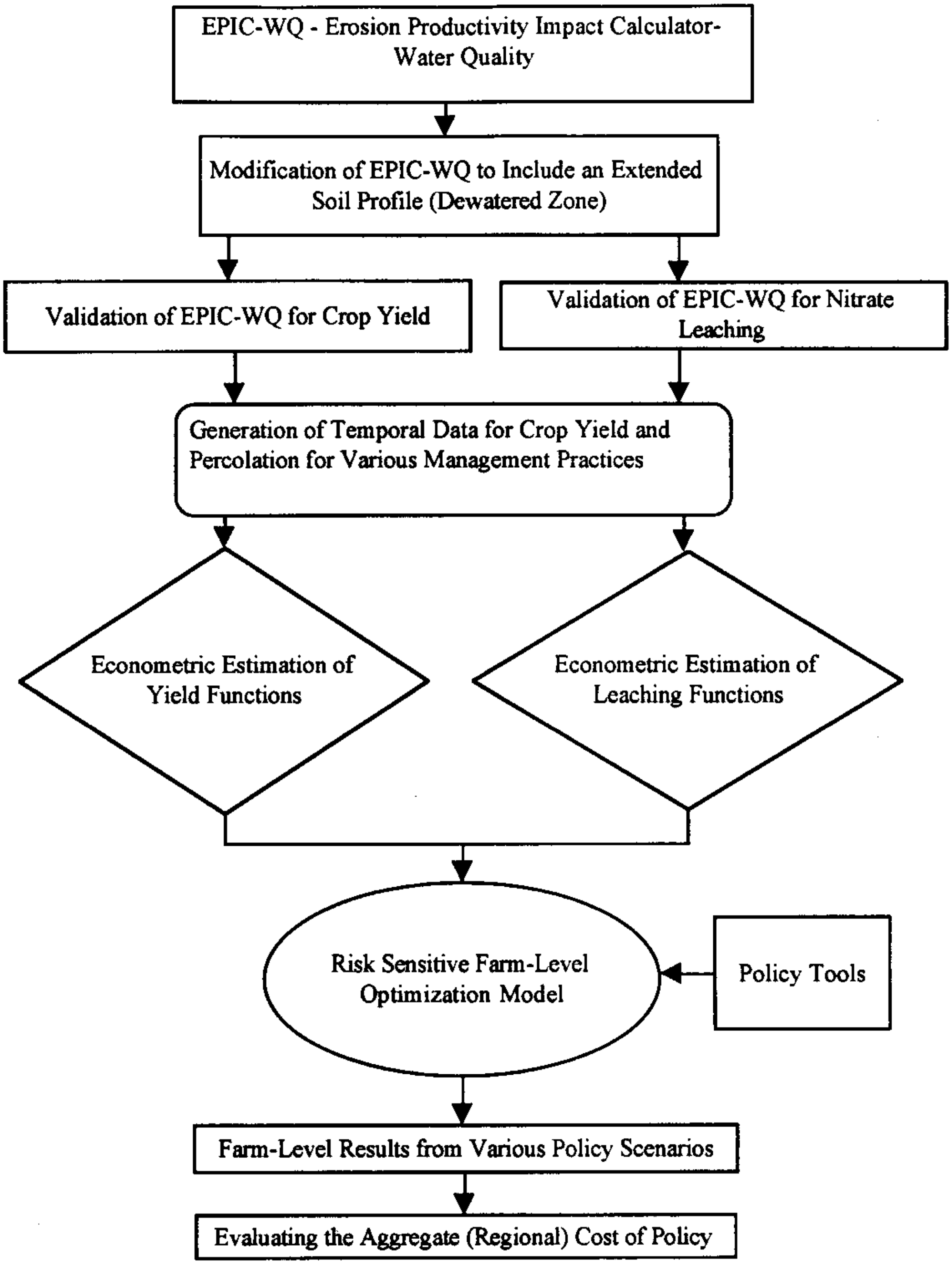

Figure 3.1. Methodology Overview

Biophysical Simulation

An inherent feature of nonpoint-sources of pollution is that flows cannot be monitored with reasonable accuracy or at reasonable cost. Furthermore, nonpoint-source pollution is stochastic in nature and influenced strongly by weather. As a result, researchers and policy analysts increasingly rely on biophysical models to estimate or predict environmental flows and simulate agronomic processes to generate a broad data set on agrichemical fate and transport. Application of these models in the water quality area allows researchers to realize many benefits, including replacing expensive field data collection with model estimates, assessing the impacts of operative actions on human health and the environment before these impacts actually occur, and screening alternative water quality policies before implementation.

During the past decade, a number of models have been developed which estimate or predict nonpoint-source pollutant flows utilizing information on farm management practices, weather, soil characteristics, and other relevant factors. If validated with site-specific data, these models can greatly diminish the uncertainty about nonpoint loadings under alternative scenarios. Over 62 models are discussed in the Ertel report along with 34 different data bases that are available. The DeCoursey report presents state-of-the-art papers on developer's and user's perspectives of nonpoint source models. Leaching models, surface runoff models, groundwater models, and lake models are examined in the report. Model application is the basis of the Resource Conservation Act (RCA) appraisal carried out by the SCS every few years. The principal issue for a user is determining the specific water quality question to define the system to be modeled (Griggs). The *Great Plains Agricultural Council Water Quality Task Force* report lists 15 of the more common models and the system that each model was designed for (Lacewell et al.).

EPIC-WQ (Erosion Productivity Impact Calculator - Water Quality) was chosen to simulate crop yields and nitrate leaching through the dewatered zone for this study. EPIC-WQ is a sophisticated process model that simulates the interaction of the soil-climate-plant-management processes in agricultural production. The model was developed by the U.S. Agricultural Research Service (ARS) in the early 1980s in response to the need for analyses of crop yield loss due to soil erosion under the Soil and Water Resources Conservation Act. Since then the model has gone through several extensive revisions and modifications.

EPIC-WQ is composed of physically-based components for processes of soil erosion, plant growth, weather, hydrology, nutrient cycling, tillage, soil temperature, and economics (Sharpley and Williams). The model simulates a small drainage area (~ 1 ha), with up to 10 soil layers within two meters. The model runs on a daily time step. A stochastic weather generator is used to provide daily temperature, precipitation, relative humidity, solar radiation, and wind values. Water erosion processes are modeled on an individual storm basis by a choice of three erosion equations: USLE, the Onstad-Foster modification of USLE (Onstad and Foster), and the modified Universal Soil Loss Equation (MUSLE) (Williams 1975). Crop growth is simulated by a generic crop growth model capable of simulating 22 crops. The tillage component simulates mixing of crop residue and nutrients in the plow layer, soil bulk density changes, and conversion of standing residue to flat residue by management operations and weather. Hydrologic and nutrient cycling components simulate a number of nutrient fluxes important to surface water and groundwater quality. These include N losses in surface runoff, subsurface transport, percolation, organic N transport by sediment, soluble P loss in runoff, and P transport by sediment. More detailed explanation of EPIC model components is given by Williams, Renard and Dyke, and Sharpley and Williams.

EPIC-WQ has been tested extensively and used in a number of local, regional, and national studies of the effects of weather, soils, and agricultural management practices on crop yields, soil erosion, and nutrient cycling. The model has been applied for a variety of purposes including determining erosion impacts on crop productivity (Putnam et al.), estimating the productive life of a soil (Benson et al.), projecting climate change effects on agriculture (Stockle et al.), and addressing agricultural effects on water quality (Meisinger et al.). EPIC-WQ has been employed successfully for numerous sites in the U.S. as well as in other countries (Cabelguenne et al.; Jones and O'Toole).

Modification of EPIC-WQ for Dewatered Zone

EPIC-WQ is a crop growth simulation model and its soil database maintains a two-meter soil data profile for different regions of the country. This precludes simulation of nitrate leaching through the dewatered zone. To modify the EPIC-WQ model by incorporating the dewatered zone, thirty six well logs were selected from a Texas Department of Water Resource's study on the Seymour aquifer (Harden and Associates). These wells are situated around the town of Munday (Knox County, Texas). The average depth of these wells is about 26-27 feet, the same as the average depth to water across the Seymour aquifer area. With the help of EPIC-WQ model developers (Williams 1992; Benson), the dewatered zone was divided into five layers and these layers were added below the top soil in the EPIC-WQ model. According to the well logs, these soil layers of the vadose zone is composed of sand, clay, silt, gravel, and caliche. The well logs give only a rough description of the soil profile, which is widely variable in the dewatered zone. Thus, some generalization about the soil profile was necessary. For example, if the well log described a soil layer as 'clay and caliche', then it was assumed that the soil profile is composed of 50% clay and 50% caliche.

Estimates of bulk density, hydraulic conductivity etc. were used by consulting soil scientists at the Texas A&M University (Milford).

Validation of EPIC-WQ for Crop Yield

A necessary step in applying biophysical simulation models is that coefficients and processes must be validated to reflect local conditions. Such validation is necessary to ensure that results are applicable to the study area. Williams et al. (1989) reviewed 227 tests of EPIC to simulate yields of six major crop species, including corn and soybeans. They found that the simulated yields were always within 7% of the mean measured yields and were not significantly different from any of them.

For this research, EPIC-WQ was validated for crop yields by using the data from a nitrogen-phosphorus fertility study on irrigated cotton conducted by the Texas Agricultural Experiment Station in Munday. The data include type, quantity, and timing of fertilizer, irrigation, and pesticide applications as well as the soil type and various tillage operations. Using the actual recorded daily weather for the area, EPIC-WQ simulated irrigated cotton yield with a negligible 5% error (629 lb./ac. actual yield versus 661 lb./ac. EPIC simulated yield). For dryland cotton and dryland wheat, the model was validated by using the yield data from the Soil Conservation Service (Seymour Aquifer Hydrologic Unit Project) in Haskell. The simulated yields obtained from the EPIC-WQ closely approximate the SCS yields (Seymour Aquifer Hydrologic Unit Project). The simulated yield for dryland cotton was also about 5% higher than actual yield (316 lbs./ac simulated vs. 300 lbs. actual). For dryland wheat, the simulated yield was about 14% higher than the actual yield (23 bushels/ac. simulated vs. 20 bushels/ac. actual). Data on nitrate in irrigation water and nitrate in soil was taken from local well testing and soil testing results conducted by the Soil Conservation Service.

Validation of EPIC-WQ for Nitrate Leaching

Proper validation of EPIC-WQ for nitrate leaching is complicated by a lack of data on nitrate leaching for the area. The data for crop yields are more accessible because field studies for crop yield have been conducted for many years. Information on nitrate and other groundwater contaminants requires expensive well testing and monitoring which are not conducted in every region. As a result, validation of EPIC-WQ for nitrate percolation has not been as extensive as the validation studies for crop yields. The soil erosion component of EPIC has been tested and validated extensively (Smith et al. 1990; Williams 1975). Comparisons of EPIC nutrient cycling predictions with field measurements over extended periods of time have also shown generally good agreement for N and P pools and fluxes (Jones, Sharpley and Williams; Jones, Cole and Sharpley; Smith, Sharpley and Nicks). Williams and Kissel found that EPIC predictions of water percolation and N leaching agreed closely with a leaching index based on soil characteristics and seasonal precipitation.

The United States Geological Survey (USGS) identified the eastern part of the Gilliland/Truscott segment of the Seymour aquifer as the study area for a project. The Gilliland/Truscott segment is small and isolated from the main segment of the Seymour aquifer without any intensive agricultural production activities. If agriculture is a major contributor to high nitrate concentration in the Seymour, then this area is expected to have lower levels of nitrate concentration. One of the objectives of this USGS study is to test this hypothesis by conducting some well testing in the area (Bartolino). Results from USGS well testing (wells drilled in 1992) were used to validate EPIC-WQ for nitrate percolation in the Seymour aquifer. Although nitrate concentration levels for many wells were available, the detailed well logs (description of the soil profile) were available only for a few wells. Furthermore, since earlier nitrate levels for the exact location are not available, it cannot be known whether the nitrate level found in these wells is in equilibrium or not. By using the well logs and by simulating native pasture production for fifty years, nitrate leaching results were obtained from EPIC-WQ. These results were then compared with the actual nitrate levels in wells drilled by the USGS. EPIC-WQ simulation of native pasture scenario for two wells were 6.2 ppm and 5.7 ppm compared to actual well tests of 9.3 ppm and 8.4 ppm, respectively. This suggests that the EPIC-WQ generated value may be lower than actual, but the relationship of one value to another is in the right direction. Continued monitoring of nitrate percolation is needed to improve the confidence in EPIC-WQ simulations.

Econometric Estimation of Response Functions

Simulation models generate a large amount of output. It is advantageous to synthesize this data from simulation models into clear and concise results. Response functions can be estimated to define the functional relationship between crop yield, fertilizer use, irrigation use, tillage practice, nitrogen percolation, and other variables. These functional relationships provide a convenient method of generating expected outcomes associated with specified levels of the variables without having to apply the simulation or process model each time. With many possible input combinations and management practices, the set of alternative production practices can be quite large and, thus, an additional benefit of estimating response functions is that the predicted value of any dependent variable can be found for any combination of inputs. This advantage is clear when the estimated regression equations are incorporated inside a mathematical programming model. Instead of several thousand production technologies, only a few response functions are required in the mathematical programming model.

Yield Response Functions

The specification of the crop yield response function was influenced by the consideration of timing of fertilizer application. For purposes of illustration, assume that crop yield is a function of nitrogen only and a quadratic function yields the following:

$$Y = \alpha_0 + \alpha_1 N + \alpha_2 N^2 + \varepsilon \tag{i}$$

where Y = crop yield, N = applied nitrogen, N^2 = quadratic term for applied nitrogen, and ε = stochastic disturbance term. However, crop yield and nitrate percolation are expected to be sensitive to the timing of nitrogen use - whether used in preplant application or postplant application. Preplant applications of nitrogen may be associated with higher levels of leaching and runoff, whereas late application (sidedressing), although relatively cost efficient, may also have elevated leaching of nitrogen to the aquifer. Incorporation of both variables will provide an option for split fertilizer application (using both preplant and sidedressing). Obviously, this would provide farmers with more flexibility than the strategy of single application either before planting or after planting. Incorporation of this timing factor suggests the following equation:

$$Y = \alpha_0 + \alpha_1 N_1 + \alpha_2 N_1^2 + \alpha_3 N_2 + \alpha_4 N_2^2 + \alpha_5 N_1 N_2 + \varepsilon \tag{ii}$$

where N_2 is postplant nitrogen and $N_2{}^2$ is the quadratic term for postplant nitrogen. If plotted, N_1 and N_2 can have different maximum yields if the interaction coefficient is zero or near zero (Figure 3.2). When incorporated inside the optimization model with

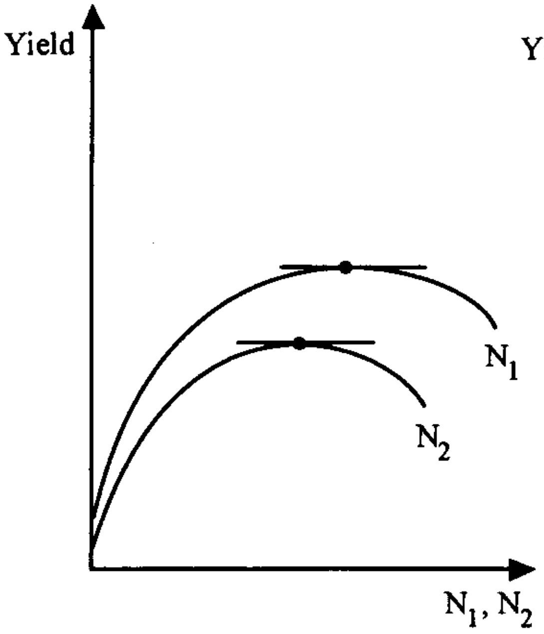

Figure 3.2. Different Maximum Yields for Preplant and Postplant Nitrogen

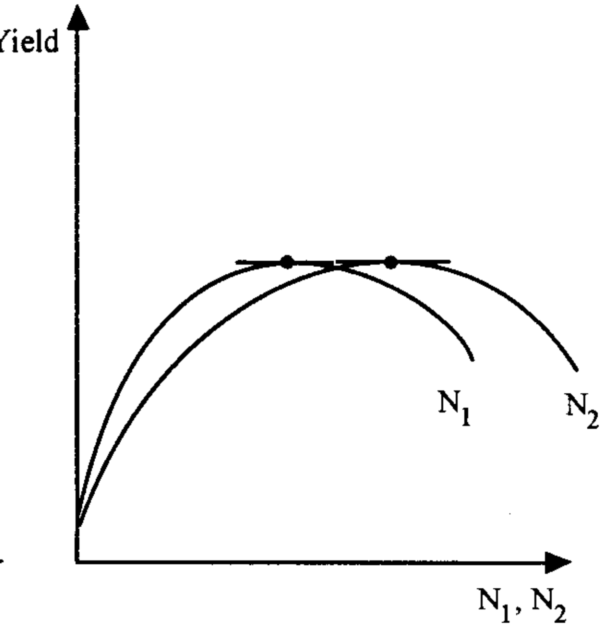

Figure 3.3. Same Maximum Yields for Preplant and Postplant Nitrogen

essentially no interdependence between N_1 and N_2, the model will choose N_1 and reject N_2 entirely, because of N_1's higher maximum yield.[5] One way of dealing with this problem is to estimate an equation so that N_1 and N_2 have the same maximum yields (Figure 3.3). The figure shows that even though N_2 is not quite as effective as N_1, both of them have the same maximum yield. The equation can be estimated by assuming the following relationship:

$$N = aN_1 + bN_2 \qquad \text{(iii)}$$

which implies that the total effectiveness of nitrogen fertilizer depends on whether it is applied in preplant or postplant application. Normalizing (dividing right side by a):

$$N = N_1 + \beta N_2 \qquad \text{(iv)}$$

where $\beta = b/a$. This implies that a postplant application of nitrogen is β times more

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[5] Although the interaction term was found to be quite small, it still was not zero. This approach thus has limitation.

effective than N_1. Substituting this in equation (i) gives:

$$Y = \alpha_0 + \alpha_1 (N_1 + \beta N_2) + \alpha_2 (N_1 + \beta N_2)^2 + \varepsilon \qquad \text{(v)}$$

This specification, where N_2 is some percent as effective as N_1 will force the model to explore all combinations of N_1 and N_2 rather than choosing and rejecting one. The split application scenarios can be easily investigated with this approach. The complete specification of irrigated cotton yield response function (shown for a modified quadratic) is as follows[6] :

$$\begin{aligned} Y = {} & \alpha_0 + \alpha_1 (N_1 + \beta N_2) + \alpha_2 (N_1 + \beta N_2)^2 + \alpha_3 R + \alpha_4 W_1 + \alpha_5 W_1^2 + \alpha_6 W_2 + \alpha_7 W_2^2 \\ & + \alpha_8 W_3 + \alpha_9 W_3^2 + \alpha_{10} W_1 W_2 + \alpha_{11} W_1 W_3 + \alpha_{12} W_2 W_3 + \alpha_{13}(N_1 + \beta N_2) W_1 \\ & + \alpha_{14} (N_1 + \beta N_2) W_2 + \alpha_{15} (N_1 + \beta N_2) W_3 + \alpha_{16}(N_1 + \beta N_2) R + \alpha_{17} W_1 R + \\ & \alpha_{18} W_2 R + \alpha_{19} W_3 R + \alpha_{20} D_1 + \alpha_{21} D_2 + \alpha_{22} D_1 (N_1 + \beta N_2) + \alpha_{23} D_1 (N_1 + \beta N_2)^2 \\ & + \alpha_{24} D_2 (N_1 + \beta N_2) + \alpha_{25} D_2 (N_1 + \beta N_2)^2 + \alpha_{26} D_1 W_1 + \alpha_{27} D_1 W_2 + \alpha_{28} D_1 W_3 \\ & + \alpha_{29} D_2 W_1 + \alpha_{30} D_2 W_2 + \alpha_{31} D_2 W_3 + \alpha_{32} D_1 W_1^2 + \alpha_{33} D_1 W_2^2 + \alpha_{34} D_1 W_3^2 \\ & + \alpha_{35} D_2 W_1^2 + \alpha_{36} D_2 W_2^2 + \alpha_{37} D_2 W_3^2 + \varepsilon \end{aligned}$$

where

Y = crop yield,

N_1 = pre-plant nitrogen fertilizer used,

N_2 = post-plant nitrogen fertilizer used,

β = a measure of effectiveness of postplant fertilizer application,

W_1 = irrigation water used in period 1 (early to mid-July),

W_2 = irrigation water used in period 2 (mid-July to early August),

W_3 = irrigation water used in period 3 (early August to late August),

W_1W_2, W_1W_3, and W_2W_3 = interactions between three irrigation periods,

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[6] The choice of functional forms is discussed in Chapter IV.

$(N_1 + \beta N_2)W_1$, $(N_1 + \beta N_2)W_2$, and $(N_1 + \beta N_2)W_3$ = interactions between fertilizer and irrigation,

$(N_1 + \beta N_2)R$ = interaction between fertilizer and rainfall,

W_1R, W_2R, and W_3R = interactions between rainfall and irrigation,

D_1 = intercept shifter of binary variable for Abilene soil,

D_2 = intercept shifter of binary variable for minimum tillage,

$D_1(N_1 + \beta N_2)$ = slope shifter of binary variable for fertilizer under Abilene soil,

$D_1(N_1 + \beta N_2)^2$ = quadratic shifter of binary variable for fertilizer under Abilene soil,

$D_2(N_1 + \beta N_2)$ = slope shifter of binary variable for fertilizer under minimum tillage,

$D_2(N_1 + \beta N_2)^2$ = quadratic shifter of binary variable for fertilizer under minimum tillage,

D_1W_1, D_1W_2, and D_1W_3 = slope shifters of binary variable for irrigation under Abilene soil,

D_2W_1, D_2W_2, and D_2W_3 = slope shifters of binary variable for irrigation under minimum tillage,

$D_1W_1^2$, $D_1W_2^2$, and $D_1W_3^2$ = quadratic shifters of binary variable for irrigation under Abilene soil,

$D_2W_1^2$, $D_2W_2^2$, $D_2W_3^2$ = quadratic shifter of binary variable for irrigation under minimum tillage.

Estimation Method

The above equation is nonlinear in coefficients and thus cannot be estimated with regular Ordinary Least Squares (OLS). The equation was estimated with a nonlinear estimation method. Nonlinear Least Squares estimates coefficients by iteratively minimizing the summed squared residuals. The initial set of starting values were obtained by estimating the linear specification of the model.

Nitrate Leaching Functions

The complete model specification (shown for semi-log specification) of a nitrate leaching function is as follows[7] :

$$\begin{aligned}\ln P = {} & \beta_0 + \beta_1 N_1 + \beta_2 N_2 + \beta_3 W_1 + \beta_4 W_2 + \beta_5 W_3 + \beta_6 R + \beta_7 N_1 N_2 + \beta_8 N_1 W_1 + \\ & \beta_9 N_1 W_2 + \beta_{10} N_1 W_3 + \beta_{11} N_2 W_1 + \beta_{12} N_2 W_2 + \beta_{13} N_2 W_3 + \beta_{14} R N_1 + \beta_{15} R N_2 \\ & + \beta_{16} W_1 W_2 + \beta_{17} W_1 W_3 + \beta_{18} W_2 W_3 + \beta_{19} D_1 + \beta_{20} D_2 + \beta_{21} D_1 N_1 + \beta_{22} D_1 N_2 \\ & + \beta_{23} D_2 N_1 + \beta_{24} D_2 N_2 + \beta_{25} D_1 W_1 + \beta_{26} D_1 W_2 + \beta_{27} D_1 W_3 + \beta_{28} D_2 W_1 + \\ & \beta_{29} D_2 W_2 + \beta_{30} D_2 W_3\end{aligned}$$

where

$\ln P$ = log of concentration of nitrate leached into the aquifer,

N_1 = Pre-plant nitrogen fertilizer used,

N_2 = Post-plant nitrogen fertilizer used,

W_1 = irrigation water used in period 1,

W_2 = irrigation water used in period 2,

W_3 = irrigation water used in period 3,

R = Rainfall,

N_1N_2 = interaction between preplant and postplant nitrogen,

N_1W_1, N_1W_2, N_1W_3, N_2W_1, N_2W_2, and N_2W_3 = interactions between nitrogen and irrigation applications,

RN_1 and RN_2 = interactions between rainfall and nitrogen fertilizer,

W_1W_2, W_2W_3, and W_1W_3 = interactions between irrigation applications,

D_1 = intercept shifter for Abilene soil type,

D_2 = intercept shifter for minimum tillage practice,

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[7] The choice of functional forms is discussed in Chapter IV.

D_1N_1, D_1N_2, D_2N_1, and D_2N_2 = slope shifters of nitrogen for Abilene soil type and minimum tillage,

D_1W_1, D_1W_2, D_1W_3, D_2W_1, D_2W_2, and D_2W_3 = slope shifters of irrigation for Abilene soil type and minimum tillage, and

ε = stochastic disturbance terms.

Estimation Method

In the case of a *censored*[8] sample some observations on the dependent variable that correspond to known sets of independent variables are zeros. In other words, the independent variables are observed for the entire sample, but the dependent variable may be zero (but not negative). In this study, nitrate percolation values comprise a censored sample since the nonzero values are only observed under certain climatic events and/or input levels. Because no value for dependent variable can occur below zero, the sample is censored at zero.

An often quoted example of censored samples originated in the pioneering work of Tobin (1958b), who analyzed household expenditure on durable goods as a function of income and other variables. It can be shown by using the Tobit model that the use of ordinary least squares (OLS) on censored sample data produces biased and inconsistent parameter estimates. Suppose that the underlying continuous version of the model is given by

$$Z_i^* = \alpha + \beta X_i^* + \varepsilon_i^*$$

Z^* might represent the expenditure on automobile purchases for those buying an automobile, or the reservation expenditure for those not buying, and X^* might represent

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[8] There is often confusion between censored samples and truncated samples. Truncated samples refer to samples for which not only the values of dependent variables are in the unobservable range but also the corresponding values of independent variables are not observed and the number of missing values is unknown.

household income. For individuals who have not bought, Z^* cannot be measured and is set equal to zero. As a result, the observed dependent variable is given by

$$Z = Z_i^* \qquad \text{for } Z_i^* > 0$$
$$Z = 0 \qquad \text{for } Z_i^* \leq 0$$

The actual estimated equation will then appear as follows:

$$Z_i = \alpha + \beta X_i + \varepsilon_i$$

For least squares to be unbiased and consistent, the mean ε_i must equal zero. However, in the above example $Z_i \geq 0$. It follows directly that $\varepsilon_i \geq - \alpha - \beta X_i$. For any particular value of X_i, the mean of ε_i can be either positive, negative, or zero. One alternative may be to ignore all observations for the Z and X variables for which Z is equal to zero, assume the dependent variable to be continuous, and use OLS estimation procedure. However, this amounts to having a truncated sample, and the OLS parameter estimates in this case are also biased and inconsistent (Maddala 1983; Amemiya).

The large number of limiting observations (zeros) gives rise to computational difficulties when estimating with the Tobit model (Capps). Heckman devised a relatively simple two-stage estimation process that yields consistent estimates of α and β. In the first stage, one needs to use the Probit model to estimate the Mill's Ratio which can be used to normalize the mean of ε_i to zero and hence get consistent estimators of α and β. In the second stage, the Mill's Ratio is added as an additional explanatory variable and then the model is estimated using the Ordinary Least Squares.

As Heckman's two-step procedure ignores censored observations (zeros) in the second stage of estimation utilizing OLS, functional forms utilizing log transformation can be explored. Another attractive feature of the Heckman two-step procedure is that it allows the researcher to statistically test for sample selection bias. If the estimated coefficient associated with Mills ratio is significantly different from zero, sample selection bias exists. On the other hand if the estimated coefficient associated with the Mill's ratio is not significantly different from zero, then there is no sample selection bias that arises from using nonrandomly selected samples to estimate behavioral relationships. Moreover, since the final coefficients are estimated using OLS, all the usual goodness of fit criteria can be applied.

Risk Sensitive Farm-level Modeling

Mathematical programming is a powerful tool for analysis of resource allocation choices at the farm and sector level. Agriculturists often pose their problems in terms of inequality constraints such as upper bounds on seasonal resource availability. They are also accustomed to the existence of slack resources in some seasons while the same resources are fully utilized in other seasons. This fits naturally into an analysis via programming models. Thus, mathematical programming models provide a rather natural framework for organizing quantitative information about the supply side of agriculture, whether at the farm level or at the sector level (Hazell and Norton).

In agriculture, decisions are made subject to the prevailing farm's physical and resource constraints and often in the face of considerable uncertainty about the planning period ahead. Uncertainty may arise in yields, costs, and prices for the individual farm enterprises, in enterprise requirements for fixed resources, and in the total supplies of the fixed resources available. The development of nonlinear programming models and structures makes it convenient to incorporate risk in a farm level context. Another advantage of mathematical programming models at the farm level context is in estimating the implications of different resource endowments or different policy scenarios. The farm level analysis is particularly suitable for a small watershed like the Seymour aquifer because of its reasonably homogenous farming system. Optimization models in this case are expected to articulate the goals and constraints of representative farmers and can provide insight into alternative outcomes associated with alternative policies.

A farm-level model was developed for a case farm in the Seymour aquifer region. About 90-95 percent of the farmers participate in the farm program (Bevers) and the analysis was therefore done for a participating farmer in the cotton and wheat program. The following is the algebraic formulation of the farm-level model used in this study. The model was programmed in GAMS (General Algebraic Modeling System) (Brooke, Kendrick, and Meeraus).

Maximize

$$(1) \qquad \text{MEANINCOME} - \O \left[\sum_{k} P_k \left\{ (\text{DEV}_k^{+})^2 + (\text{DEV}_k^{-})^2 \right\} \right]^{1/2}$$

Subject to

$$(2) \qquad \sum_{crop} \sum_{n_1} \sum_{n_2} \sum_{w_1} \sum_{w_2} \sum_{w_3} \sum_{s} \sum_{t} \text{ACRES}_{\text{target price, crop, n1, n2, w1, w2, w3, s, t}} \leq$$

$$\sum_{crop} \text{BASEACRES}_{crop} * (1 - \text{SETASIDERATE}_{crop} - \text{NORMFLEX})$$

$$(3) \qquad \sum_{crop} \sum_{n_1} \sum_{n_2} \sum_{w_1} \sum_{w_2} \sum_{w_3} \sum_{s} \sum_{t} \text{ACRES}_{\text{market price, crop, n1, n2, w1, w2, w3, s, t}} \geq$$

$$\sum_{crop} \text{BASEACRES}_{crop} * \text{NORMFLEX}$$

$$(4) \qquad \text{SETASIDELAND} \geq \sum_{crop} \text{BASEACRES}_{crop} * \text{SETASIDERATE}_{crop}$$

$$(5) \qquad \sum_{crop} \sum_{fp} \sum_{n_1} \sum_{n_2} \sum_{w_1} \sum_{w_2} \sum_{w_3} \sum_{s} \sum_{t} \text{ACRES}_{fp,\, crop,\, n_1,\, n_2,\, w_1,\, w_2,\, w_3,\, s,\, t}$$

$$+ \ \text{SETASIDELAND} \ \leq \text{TOTALLAND}$$

(6)

$$\sum_{fp}\sum_{n_1}\sum_{n_2}\sum_{w_1}\sum_{w_2}\sum_{w_3}\sum_{s}\sum_{t} \text{ACRES}_{fp,\ \text{dry-cotton},\ n_1,\ n_2,\ w_1,\ w_2,\ w_3,\ s,\ t} \geq \frac{1}{3} \ *$$

$$\sum_{fp}\sum_{n_1}\sum_{n_2}\sum_{w_1}\sum_{w_2}\sum_{w_3}\sum_{s}\sum_{t} \text{ACRES}_{fp,\ \text{dry-cot-wht-rot},\ n_1,\ n_2,\ w_1,\ w_2,\ w_3,\ s,\ t}$$

(7)

$$\sum_{fp}\sum_{n_1}\sum_{n_2}\sum_{w_2}\sum_{s}\sum_{t} \text{IRRIG-LEVELS}_{w2} * \text{ACRES}_{\text{irrig-cotton},\ fp,\ n1,\ n2,\ w2,\ s,\ t} \leq \text{AVWAT2}$$

(8)

$$\sum_{fp}\sum_{n_1}\sum_{n_2}\sum_{w_3}\sum_{s}\sum_{t} \text{IRRIG-LEVELS}_{w3} * \text{ACRES}_{\text{irrig-cotton},\ fp,\ n1,\ n2,\ w3,\ s,\ t} \leq \text{AVWAT3}$$

(9)

$$\sum_{fp}\sum_{n_1}\sum_{n_2}\sum_{w_1}\sum_{w_2}\sum_{w_3}\sum_{s}\sum_{t} \text{ACRES}_{\text{irrig-cotton},\ fp,\ n1,\ n2,\ w1,\ w2,\ w3,\ s,\ t}$$

$$\leq \text{TOTAL-IRRIG-ACREAGE}$$

(10)

$$\sum_{crop}\sum_{fp}\sum_{n_1}\sum_{n_2}\sum_{w_1}\sum_{w_2}\sum_{w_3}\sum_{s}\sum_{t} \text{PERACREINCOME}_{crop,\ fp,\ n_1,\ n_2,\ w_1,\ w_2,\ w_3,\ s,\ t,\ k}$$

$$* \text{ACRES}_{crop,\ fp,\ n_1,\ n_2,\ w_1,\ w_2,\ w_3,\ s,\ t} - \text{INCOME}_k = 0 \qquad \text{for all } k$$

(11)

$$\sum_{k} P_k\, \text{INCOME}_k - \text{MEANINCOME} = 0$$

(12)

$$\text{INCOME}_k - \text{MEANINCOME} - \text{DEV}_k^{+} + \text{DEV}_k^{-} = 0 \qquad \text{for all } k$$

(13)

$$\text{NL}_{crop,\ n_1,\ n_2,\ w_1,\ w_2,\ w_3,\ s,\ t} * \ \text{ACRES}_{crop,\ fp,\ n_1,\ n_2,\ w_1,\ w_2,\ w_3,\ s,\ t}$$

$$\leq \ \text{EPA-STANDARD} * \ \text{ACRES}_{crop,\ fp,\ n_1,\ n_2,\ w_1,\ w_2,\ w_3,\ s,\ t}$$

(14)

$$\sum_{crop}\sum_{fp}\sum_{n_1}\sum_{n_2}\sum_{w_1}\sum_{w_2}\sum_{w_3}\sum_{s}\sum_{t} \text{NL}_{crop,\ fp,\ n_1,\ n_2,\ w_1,\ w_2,\ w_3,\ s,\ t} \ *$$

$$\text{ACRES}_{crop,\ fp,\ n_1,\ n_2,\ w_1,\ w_2,\ w_3,\ s,\ t} \leq \sum_{crop}\sum_{fp}\sum_{n_1}\sum_{n_2}\sum_{w_1}\sum_{w_2}\sum_{w_3}\sum_{s}\sum_{t}$$

$$\text{EPA-STANDARD} \; * \; \text{ACRES}_{\text{crop, fp}, \, n_1, \, n_2, \, w_1, \, w_2, \, w_3, \, s, \, t}$$

$$(15) \qquad \text{ACRES}_{\text{crop, fp}, \, n_1, \, n_2, \, w_1, \, w_2, \, w_3, \, s, \, t} \, ; \; \text{DEV}_k^{+} \, ; \text{DEV}_k^{-} \, ; \text{SETASIDELAND} \quad \geq 0$$

$$(16) \qquad \text{INCOME}_k \, ; \; \text{MEANINCOME} \quad \gtrless 0$$

Subscripts:

k	state of nature, $k = 1, 2, \ldots\ldots, 25$
crop	major crops, crop = irrigated cotton, dryland cotton, dryland wheat
fp	farm program, fp = target price acres, market price acres
n_1	pre-plant nitrogen fertilizer levels, $n_1 = 9$ levels (20 - 60 lb. with 5 lb. interval)
n_2	post-plant nitrogen fertilizer levels, $n_2 = 5$ levels (10 - 30 lb. with 5 lb. interval)
w_1	irrigation levels during period 1, $w_1 = 2$ levels (0 or 5 inches)
w_2	irrigation levels during period 2, $w_2 = 4$ levels (0, 3, 4, and 5 inches)
w_3	irrigation levels during period 3, $w_3 = 4$ levels (0, 3, 4, and 5 inches)
s	soil type, s = Miles, Abilene
t	tillage practice, t = conventional, minimum

Parameters:

Ø	Arrow-Pratt Risk Aversion Coefficient (RAC)
P_k	probability of occurring k state of nature
TOTALLAND	total acreage available
TOTAL-IRRIG-ACREAGE	limitation on irrigated acreage
AVWAT2	available water for irrigation in period 2
AVWAT3	available water for irrigation in period 3

EPA-STANDARD	EPA standard for nitrate concentration in drinking water
NORMFLEX	Percent of base acres not eligible for deficiency payment
SETASIDERATE	percent of base acres that must be set aside for a crop
BASEACRES	acres established for farm program consideration
NL	concentration of nitrate leached

Variables:

MEANINCOME	mean farm net income (averaged over all states of nature), in $
INCOME_k	farm net income under k^{th} state of nature
ACRES	acres used in production with different management practices
DEV_k^+	positive deviation from expected income
DEV_k^-	negative deviation from expected income
ACRES	acres allocated under farm program with mgt. practices
SETASIDELAND	total set-aside land as a farm program requirement
PERACREINCOME	per acre net return

The model maximizes the objective function subject to the constraints (2) through (16). Equation (1) is the objective function which maximizes expected net income less a risk aversion coefficient (Ø) times the standard deviation of income. The risk aversion coefficient, Ø, quantifies the degree to which the decision maker is willing to trade the reduction in variability of net returns for a reduction in mean net returns. The risk aversion coefficient ø would range between 0 and 2.50 for most circumstances. The term DEV_k refers to the deviation of income from mean income under k^{th} state of nature. P_k is the probability of observing any state of nature k (which is one divided by the total number of states of nature).

Equations (2) through (4) are the farm program constraints used according to the 1994 Farm Program announcements (Smith et al. 1994). Equation (2) determines the total acres eligible for deficiency payment. Equation (3) is the normal flex requirement, i.e. percent of total base acres that are not eligible for deficiency payment. Equation (4) is the total set-aside land for crops.

A major resource requirement in the model is the availability of land for growing crops. Equation (5) is a land balance constraint indicating that the sum of acres (target price acres, flex acres, and set aside acres) cannot exceed the total available land in the case farm. A 1,500 acre case farm was used in the model.

Equation (6) represents the land rotation constraint and forces the crops to follow a specified crop rotation. Only a dryland cotton-dryland wheat rotation is permitted in the model as rotation between irrigated and dryland crops is not practiced because of the fixity of irrigation systems. A paired t-test revealed that the distribution of yields (obtained from EPIC-WQ) for dryland monoculture cotton and dryland-wheat-rotation did not have any significant difference (see Table A.1 in Appendix A). Thus with input from farmers in the region, a rotation was implemented that included wheat every third year to control weed and insect problems that may result from monoculture cotton (Bevers).

Equations (7) and (8) are period specific water availability constraints that place a limit on the acres that can be irrigated within the specific time period. The amount of water available in each period is a function of well yield (in gallons per minute) and the average number of days in each watering period not used for repairs. It is assumed that irrigation wells could potentially pump 8 days in a 10 day period (Petty).

Given the pumping capacity of wells used to operate three center pivot irrigation systems in a case farm, it is estimated that during a ten day period, 445 acres can be irrigated with 3 inches (with 1,336 acre inches of water). The center-pivot irrigation systems operate at a lower pace when more intensive irrigation is applied (4 or 5 inches) and thus less acres can be irrigated with more intensive irrigation. As the farmer has enough time to irrigate during the preplant irrigation (period 1), no water availability constraint is placed in period 1. Up to 5 inches of irrigation water is used in period 1. Equation (9) imposes a limitation on the total acres that can be irrigated. This constraint is needed so that the choice of irrigation is limited to the same 445 acres in every period.

Equation (10) is the net income balance constraint where the farm income for a state of nature is determined by calculating per acre net income and then multiplying by the number of acres used. Per acre net income was calculated by multiplying crop yields (obtained from the yield response functions) by crop prices and then subtracting all the variable costs. Fixed costs were not included in the calculation. For revenue calculation, target prices and market prices were used for deficiency-payment-acres and market-price-acres for each crop, respectively. The most recent market price of cotton and wheat for the Rolling Plains Region was used. Information on target price, was obtained from Smith et al. (1994). As farmers receive a deficiency payment based on their proven or established yield, target price is used to calculate income on the calculated yield from the response function up to the established yield. The market price is used for yield above the established yield. The average established yields are calculated by the local ASCS office (Rector). Income from livestock grazing on wheat is added in the revenue calculation. The reduced cost of minimum tillage, cost of maintaining set aside acres, additional cost of split use of nitrogen etc. are also included. Twenty five years of simulated rainfall data were used to estimate twenty five different crop yields from the rainfall coefficient of the response functions. These twenty five yields for each crop characterize twenty five states of nature.

Equation (11) determines the mean net income by calculating the net income over all states of nature. It is assumed that each state of nature has an equally likely probability of occurrence. The deviation constraint of equation (12) calculates positive and negative deviations from expected income for each state of nature. These deviations were used in the objective function equation to determine the variance.

Equation (13) and (14) are the environmental constraints where the estimated nonpoint pollution functions are used to determine nitrate leaching from various management practices. Equation (13) places a 10 parts per million (EPA standard) per acre restriction on the concentration of leaching on a per acre basis. Equation (14) is a more flexible environmental constraint where the restriction is placed in such a way so that the total farm-level concentration of nitrate leached does not exceed the EPA standard times the number of acres used for farming. Equations (15) and (16) define restrictions on variable values.

CHAPTER IV

ESTIMATED RESPONSE FUNCTIONS

Three agricultural production functions and three nonpoint pollution functions (nitrate leaching functions) were estimated for three major crops in the area. These functions were applied in the mathematical programming model and were used to develop farm-level implications of alternative production practices for water quality and agricultural profit.

Data

The data on crop yield and concentration of nitrate percolation were generated from EPIC-WQ simulations for various input combinations and management practices. The EPIC-WQ model was applied for selected levels of preplant and postplant nitrogen fertilizer application, irrigation water application across three periods, two soil types (Miles and Abilene), and two tillage practices (conventional and minimum). The irrigation periods used were early to mid-July, mid-July to early August, and early August to late August as defined in the Seymour Aquifer HUA Project Crop Enterprise Budget. A preplant and/or postplant fertilizer application was considered with seven levels of preplant and postplant fertilizer (20 to 80 pounds at 10 pound intervals) and 3 levels of irrigation application in each period (3, 5 and 7 inches) were used for irrigated cotton. Combinations of seven levels of preplant and postplant fertilizer (20 to 80 pounds at 10 pound intervals) were used for dryland wheat. For dryland cotton, only five levels of fertilizer (20 to 60 pounds at 10 pound intervals) were used. The same input levels were used to generate the data under alternative soils and tillage practices which were used as binary variables. The total number of observations were 4,900, 700, and 700 for irrigated cotton, dryland cotton, and dryland wheat, respectively. The simulations were conducted for twenty five years. Corresponding rainfall data for twenty five years were generated by applying the stochastic weather data in EPIC-WQ. The data set for nitrate percolation turned out to be censored as nitrate leaching occurred only on certain years, depending on weather.

Diagnostic Tests

Diagnostic tests were performed to detect the presence of multicollinearity, heteroskedasticity, autocorrelation, and influential observation (s). These tests provide insight into the reliability of coefficient estimates, i.e. whether the estimated coefficients are unbiased, consistent, and efficient.

Multicollinearity

The diagnostic tests for multicollinearity is to determine the level of multicollinearity in an equation, not whether multicollinearity exists or not. The explanatory variables are going to be at least slightly related to each other, and so the important consideration is the degree of multicollinearity.

Since multicollinearity is not the kind of problem that an equation either has or doesn't have, many of the methods used to detect multicollinearity are not formal tests with critical values or levels of significance. In fact, there is no universally accepted test of multicollinearity. Instead, most researchers develop a general feeling for the severity and importance of multicollinearity in an equation by looking at a number of the characteristics of the estimated equation. One of the unique consequences of multicollinearity is that the overall level of significance of an equation is affected far less than the levels of significance of the individual regression coefficients. Given this fact, one of the first indications of the possible presence of severe multicollinearity is the combination of a very high R^2 with low calculated t-values for the individual regression coefficients. The estimated functions did not show unusually high R^2 or low t-values. Using 30 as the cutoff value for condition index (Belsley, Kuh, and Welsch) no multicollinearity was detected.

It is said that if the purpose of regression analysis is prediction, then multicollinearity is not a serious problem (Geary; Maddala 1977). Because when the purpose is prediction, the emphasis is on "groups" of estimates (i.e. derivatives) rather than individual coefficient estimates. Any observed multicollinearity will mostly occur within a group rather than across the group.

Even in the presence of multicollinearity, most often doing nothing is the correct course of action because every remedy for multicollinearity has a drawback. A remedy should only be considered if and when the consequences cause too many insignificant t-ratios or wildly unreliable coefficients. Any remedy for multicollinearity could potentially cause other problems for an equation.[9] Thus, in reviewing the models estimated here, multicollinearity was not considered to be a severe problem that would distort the research results.

Heteroskedasticity

An important assumption of the classical regression model is that the disturbances appearing in the population regression function are homoskedastic, i.e. they all have the same variance. When this assumption of constant variance is violated, they are known to be heteroskedastic. Under heteroskedasticity, the OLS estimators are still unbiased and consistent, but they are no longer efficient.

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[9] "In a sense, collinearity is similar to a non-life-threating human disease that requires general anesthesia to operate on; the risk of the operation should only be undertaken if the disease is causing a significant problem." (Studenmund and Cassidy).

The problem of heteroskedasticity is more commonly encountered in cross-sectional data. In this study, for example, crop yield data is generated for various levels of nitrogen and irrigation applications. Since the responsiveness of crop yield reduces at higher levels of fertilizer application, the variability of yield is expected to be lower at high levels of fertilizer use compared to low levels of use. Thus, some degree of heteroskedasticity is expected to be present. Tests for heteroskedasticity were conducted by using *Het* option in SHAZAM (White). The Chi-square statistic of Breusch-Pagan-Godfrey test, Arch test, Harvey test, and Glejser test were compared with the critical value of Chi-square distribution at 5% level of significance. No heteroskedasticity was found for irrigated cotton. This is because irrigation application reduces the variability of yield. For dryland cotton and wheat, the heteroskedasticity was mild and correction for heteroskedasticity was found to be unnecessary given the degree of heteroskedasticity.

Heckman two-step procedure, used to estimate the nitrate leaching functions, is known to introduce heteroskedasticity (Amemiya). However, compared to other methods of limited dependent variable, it has several advantages. Furthermore, the log-linear function (found to be have the best statistical fit for nitrate leaching functions) is expected to reduce heteroskedasticity (Gujarati). The log transformation compresses the scales in which the variables are measured, thereby reducing a tenfold difference between two values to a two-fold difference.[10]

Autocorrelation

With autocorrelation, the estimators are unbiased, consistent, but not efficient. However, "...there is likely to be intercorrelations among successive observations especially if the time interval between successive observations is short, such as a day, a

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[10] The number 80 is 10 times the number 8, but ln 80 (= 4.3820) is only twice as large as ln 8 (=2.0794)

week, or a month rather than a year." (Gujarati). "Thus we would be more suspicious of the presence of autocorrelation when dealing with monthly or quarterly observations than when the data are given at annual intervals." (Kmenta). The data used for this study are annual observations and using the *EXACTDW* option in SHAZAM, no significant autocorrelation was found.

Influential Observations

Frequently in regression analysis applications, the data set contains some observations that are outlying or extreme, i.e. the observations for these cases are well separated from the remainder of the data. These outlying cases may involve large residuals and often have dramatic effects on the fitted least squares regression function. It is therefore customary to study the outlying cases carefully and decide whether they should be retained or eliminated.

Tests for influential observations were conducted with the "influence" option in SHAZAM. The usual tests involve examining Hat Diagonal, R-student, DFFITS and DFBETAS. Several outlying observations were detected. However, an outlying influential case should not be automatically discarded, because it may be entirely correct and simply represents an unlikely event. Discarding of such an outlying case could lead to the undesirable consequence of increased variances of some of the estimated regression coefficients. Most importantly, since the data is obtained from EPIC-WQ model, the influential observation may have occurred because of some biophysical event (for example, an extreme weather scenario). Thus, no outlying observations were discarded.

Yield Response Functions

The Choice of Functional Form

Functional form presents a challenge in applying regression techniques. The purpose here was to choose the best form for a given task. This problem leads to consideration of choice criteria, i.e. how one functional form may be judged better or more appropriate than another. The choice criteria for functional form in this study was based on whether the forms impose a positive yield for a zero input level and also whether the first derivatives of the functional forms are unrestricted in sign and value. The first criterion is needed because a certain positive yield is observed for zero input as some level of soil moisture and soil nutrient is usually available to the plant. The criterion would also permit the optimization model to consider a combination of inputs where one or more input level is zero. EPIC-WQ simulation of crop yield without any applied input shows a very low positive yield. The second criterion is used because the objective of fitting crop production functions is not only to describe crop yield response to inputs but also to estimate the optimum input levels. It is, therefore, necessary to select functional forms which would allow marginal products to increase and then decrease.

Four polynomial functional forms (three-halves, quadratic, square root, and the cubic) were identified for this study. Estimation of the full cubic model with all terms showed wrong coefficient signs. Elimination of many insignificant coefficients and reestimation resulted in a function which could not be called 'cubic'. Thus, the cubic form was not considered. Some additional interaction terms between variables were used for the rest of the polynomial forms mentioned above. As a result, the forms slightly deviate from the typical polynomial form. The selected equations are therefore 'modified' polynomials.

Although the choice of form depends on the problem being investigated and also on the nature of data and other considerations, a majority of studies in the literature demonstrated preference for polynomial forms. Polynomial forms have been preferred in the literature because they allow specification of the joint effect of water and other inputs as well as incorporate negative marginal productivity (e.g., McSweeny and Shortle, Dai et al., Griffin et al., Feinerman et al., and Hexem and Heady).

Having selected a set of functional forms based on a choice criteria, the next step was to select the final form based upon a statistical criterion. Using the highest R^2 and the lowest Schwarz criterion, the modified quadratic was chosen for irrigated cotton and dryland wheat and a modified three-halves was chosen for dryland cotton. Table 4.1 reports R^2 and Schwarz criterion for the alternative functional forms.

Table 4.1. Goodness of Fit for Alternative Functional Forms: Yield Response Function

Functional Form	Schwarz Criterion			R^2		
	Irrig-Cotton	Dry-Cotton	Dry-Wheat	Irrig-Cotton	Dry-Cotton	Dry-Wheat
Quadratic	9.28	9.58	9.39	0.614	0.493	0.592
Square-root	9.94	9.71	9.89	0.487	0.429	0.394
Three-halves	9.67	9.35	9.76	0.514	0.627	0.416

As mentioned above, a modified quadratic form resulted in the best fit for irrigated cotton and dryland wheat whereas a modified three-halves form had the best fit for dryland cotton. The equations were reestimated after eliminating coefficients which were not significant at the 20% level. There exists a debate on the appropriateness of eliminating or not eliminating statistically insignificant variables when the purpose is prediction. Pretesting is an important issue when some insignificant coefficients are dropped. However, it is not expected that the results would be very different if the insignificant variables were retained.

The final model specification of irrigated cotton response function is as follows. The description of variables was presented in chapter III (page 43 - 44).

$$\begin{aligned} Y = {} & \alpha_0 + \alpha_1 (N_1 + \beta N_2) + \alpha_2(N_1 + \beta N_2)^2 + \alpha_3 R + \alpha_4 W_1 + \alpha_5 W_1^2 + \alpha_6 W_2 + \alpha_7 W_2^2 \\ & + \alpha_8 W_3 + \alpha_9 W_3^2 + \alpha_{10} W_1 W_2 + \alpha_{11} W_1 W_3 + \alpha_{12} W_2 W_3 + \alpha_{13}(N_1 + \beta N_2) W_1 \\ & + \alpha_{14} (N_1 + \beta N_2) W_2 + \alpha_{15} D_1 + \alpha_{16} D_1 W_1^2 + \alpha_{17} D_1 W_2^2 + \alpha_{18} D_1 W_3^2 + \varepsilon \end{aligned}$$

The coefficient estimates and t-values for the above function are shown in Table 4.2. Although use of statistical tests when fitting functions to simulated data is suspect, the t-values of the estimated coefficients show that all coefficients are significant at the 10% level. The critical t-values are 1.645 and 1.282 for 10% and 20% significance levels, respectively. β is 0.88 implying that the post-plant fertilizer application is only 88% as effective as the pre-plant application. The quadratic terms for nitrogen and irrigation equation have a negative sign indicating that crop yield eventually declines. The coefficient of α_{15} shows that irrigated cotton yield is about 48 lbs/ac. higher in the Abilene soil. Because of the presence of interaction terms, a Wald test (Kmenta, p. 492) was conducted to test the significance of variables. The Wald Chi-square statistic was compared with the critical Chi-square values and all the variables were significant at the 5% level.

The final model specification of the dryland cotton yield response function is as follows:

$$\begin{aligned} Y = {} & \alpha_0 + \alpha_1 (N_1 + \beta N_2) + \alpha_2(N_1 + \beta N_2)^{1.5} + \alpha_3 R + \alpha_4 D_1 + \alpha_5 D_1(N_1 + \beta N_2) + \\ & \alpha_6 D_2(N_1 + \beta N_2) + \varepsilon \end{aligned}$$

The estimated coefficients for dryland cotton are presented in Table 4.3. The description of variables were presented in chapter III (page 43-44). The Wald Chi-square statistic shows that all coefficients are significant at 5% level of significance. Unlike irrigated cotton, the slope shifter of nitrogen for minimum tillage is significant, although the magnitude of the coefficient is small. The effect of rainfall on dryland cotton is greater than for irrigated cotton. This is because under dryland cotton, there is a considerable amount of water stress and crop yield is highly sensitive to soil moisture. The coefficient of α_4 shows that dryland cotton yield would be about 33 lbs./ac. higher for the Abilene soil. The slope shifters of nitrogen for Abilene soil and minimum tillage are significant, implying a different yield effect to nitrogen for the Abilene soil and minimum tillage compared to the Miles soil.

The final model specification of the dryland wheat yield response function is as follows:

$$Y = \alpha_0 + \alpha_1 (N_1 + \beta N_2) + \alpha_2(N_1 + \beta N_2)^2 + \alpha_3 R + \alpha_4 D_1 + \alpha_5 D_2 + \varepsilon$$

The estimated coefficients of the yield response function for dryland wheat is presented in Table 4.4. The description of variables was presented in chapter III (page 43-44). Results of the Wald test indicate that all estimated coefficients are significant at a 5% level of significance. The intercept shifter for the Abilene soil (α_4) indicates that the yield would be 1.09 bushels/ac. higher on a Abilene soil than a Miles soil. The coefficient of α_5, the intercept shifter for minimum tillage, indicates that yield would be about 0.81 bushels/ac. lower when minimum tillage is used with no variable inputs. Unlike dryland cotton, the slope shifter of minimum tillage (α_6) shows that the change in yield due to nitrogen fertilizer with minimum tillage would be slightly higher than for conventional tillage.

Table 4.2. Coefficient Estimates of Crop Yield Response Function : Irrigated Cotton

Coefficients	Estimated Value	T-Ratio	Coefficients	Estimated Value	T-Ratio
α_0	90.33	17.250	α_{10}	0.0231	4.3093
α_1	2.851	14.345	α_{11}	0.0187	1.7702
α_2	-0.0251	-10.930	α_{12}	0.0201	4.1760
α_3	10.34	63.674	α_{13}	0.0033	2.1445
α_4	31.04	23.311	α_{14}	0.0029	1.9152
α_5	-2.630	-16.272	α_{15}	48.103	12.183
α_6	32.10	23.678	α_{16}	-0.2430	-2.6139
α_7	-2.810	-16.904	α_{17}	-0.3590	-3.8680
α_8	28.03	20.010	α_{18}	-0.3635	-3.9090
α_9	-2.360	-14.377	β	0.8813	5.6780

R^2(adjusted): 0.6144
Schwarz Criterion: 9.28

Table 4.3. Coefficient Estimates of Crop Yield Response Function: Dryland Cotton

Coefficients	Estimated Value	T-Ratio
α_0	49.437	2.6151
α_1	10.4819	2.6745
α_2	-1.11689	-2.1483
α_3	20.076	13.496
α_4	33.607	1.8916
α_5	0.1258	1.3478
α_6	-.0340	-1.7665
β	0.81	4.9320

R^2 (adjusted): 0.627
Schwarz Criterion: 9.356

Table 4.4. Coefficient Estimates of Crop Yield Response Function: Dryland Wheat

Coefficients	Estimated Value	T-Ratio
α_0	7.654	16.517
α_1	0.4526	15.634
α_2	-0.0039	-11.698
α_3	0.7423	18.873
α_4	1.0984	1.7051
α_5	-0.8193	-1.5231
β	0.8205	13.784

R^2 (adjusted): 0.592
Schwarz Criterion: 9.39

Nitrate Leaching Functions

The Choice of Functional Forms

Unlike production function analysis, estimation of a nonpoint emission function is not a common practice and as such one cannot infer about the shape of the function, *a priori*. The main criterion used for choosing among alternative functional forms was whether the forms allowed certain leaching to occur even if no inputs were used. This choice criterion is important because some nitrate percolation results from natural organic nitrogen in the soil. The issue is particularly important for the Seymour aquifer area where a portion of nitrate contamination is sometimes argued to have originated from natural soil nitrates. EPIC-WQ simulation of native pasture showed a positive percolation of nitrates. Allowing an intercept for the leaching function resulted in the initial selection of six functional forms: linear, semi-log, cubic, quadratic, square-root, and three-halves. The linear form showed a poor fit supporting the assumption that nitrate leaching is a complicated and highly nonlinear process. The cubic form was not chosen because of the same reason mentioned under yield response function. The final selection was made from semi-log, quadratic, square-root and three-halves. Using the highest R^2 and the lowest Schwarz criterion, the semi-log (log of dependent variable) form resulted in the best statistical fit for all crops. Table 4.5 reports R^2 and Schwarz criterion for the alternative functional forms. Because of log transformation, adjustments were made in the calculation of R^2 (Studenmund and Cassidy, p.154). The semi-log form implies that concentration of nitrate is relatively low for low fertilizer use but gradually it increases at increasing rates of fertilizer application which satisfies intuition.

Table 4.5. Goodness of Fit for Alternative Functional Forms: Nitrate Leaching Function

Functional Form	Schwarz Criterion			R^2		
	Irrig-Cotton	Dry-Cotton	Dry-Wheat	Irrig-Cotton	Dry-Cotton	Dry-Wheat
Semi-log	-0.417	-0.428	-0.429	0.592	0.490	0.554
Quadratic	-0.429	-0.439	-0.438	0.481	0.417	0.469
Square-root	-0.467	-0.472	-0.479	0.392	0.315	0.306
Three-halves	-0.438	-0.447	-0.449	0.457	0.396	0.414

The coefficient estimates for an irrigated cotton nitrate leaching function (after eliminating insignificant coefficients and reestimating) are reported in Table 4.6. The definition of variables was presented in chapter III (page 45-46). As the function is in

Table 4.6. Coefficient Estimates of Nitrate Leaching Function: Irrigated Cotton

Variable Name	Estimated Coefficients	T-Ratio
N_1	0.02738	8.1202
N_2	0.01836	7.683
R	-0.2226	-24.312
W_1	0.04395	2.4271
W_2	0.02780	1.6569
W_3	0.04981	2.6684
N_1N_2	0.000145	4.1853
RN_2	-0.00052	-3.4697
W_1W_2	0.00556	2.6761
W_1W_3	-0.00324	-1.9577
W_2W_3	0.00428	2.0472
D_1	0.10363	3.1195
D_1N_1	0.00221	3.9247
D_1N_2	0.00243	3.4776
D_2N_1	-0.00231	-1.3596
Constant	1.90130	6.7482

R^2 (adjusted) : 0.5928
Mills Ratio: 3.8945 (t-ratio: 1.279)
Schwarz Criterion: -0.4176

log form, the coefficients must be translated back to anti-log (by taking the exponential) after multiplying by the quantity of input. Because of the presence of interaction terms, a Wald test was calculated to test the significance of variables. All variables are significant at the 5% level. The negative coefficients for rainfall variables and interaction terms between rainfall and postplant nitrogen shows the effect of rainfall on nitrate concentration, i.e. rainfall reduces the concentration of nitrate. Concentration of nitrate associated with irrigation has a positive relationship because of the presence of nitrate in the irrigation water. However, the magnitude of the coefficients (W_1, W_2, and W_3) is small. Nitrate concentration in irrigation water was assumed to be 12 ppm. There are cases where the concentration of nitrate in irrigation water exceeds 50 ppm . With such high concentration, percolation of nitrates would be expected to increase due to irrigation. The intercept and slope shifters of the Abilene soil are positive and significant, implying that the concentration of nitrate percolation would be higher in an

Abilene soil. The slope shifter of minimum tillage indicates that the concentration of nitrate would decrease under minimum tillage although the magnitude is rather small.

Table 4.7 shows the coefficients for the dryland cotton leaching function. The definition of variables were presented in chapter III (page 45-46). The Wald test showed that all coefficients are significant at the 5% percent level. The coefficient of D_2 shows that the concentration of percolation would be slightly lower (by $e^{.0014}$ ppm or 1.0 ppm) when minimum tillage is used. The coefficients of D_1N_1 and D_1N_2 indicate that percolation would be higher under an Abilene soil.

The estimated coefficients for dryland wheat are reported in Table 4.8. The definition of variables were presented in chapter III (page 45-46). The Wald Chi-square statistic showed that all coefficients are significant at the 5% level. The coefficient of D_1 (intercept shifter for Abilene soil), D_1N_1 (slope shifter of preplant nitrogen for Abilene soil), and D_1N_2 (slope shifter of postplant nitrogen for Abilene soil) shows that concentration of nitrate percolation would be higher in Abilene soil.

Table 4.7. Coefficient Estimates of Nitrate Leaching Function: Dryland Cotton

Variable Name	Estimated Coefficients	T-Ratio
N_1	.04143	2.8930
N_2	.03379	2.0765
N_1N_2	.000251	2.9826
R	-.0219	-4.1425
RN_1	-.00013	-2.4170
RN_2	-.00015	-2.3792
D_1	.0970	2.6249
D_2	-.0014	-1.9723
D_1N_1	.0021	1.7105
D_1N_2	.0017	1.9219
Constant	1.40	2.2680

R^2 (adjusted): 0.4902
Mills Ratio: 4.2054 (t-ratio: 1.022)
Schwarz Criterion: -0.428

Table 4.8. Coefficient Estimates of Nitrate Leaching Function: Dryland Wheat

Variable Name	Estimated Coefficients	T-Ratio
N_1	.014643	2.0404
N_2	.0135	2.4521
N_1N_2	-.00019	-3.0296
R	-.0240	-11.312
D_1	.1130	3.0946
D_1N_1	.00263	1.8933
D_1N_2	.002212	1.7634
Constant	1.7567	6.7687

R^2 (adjusted): 0.5540
Mills Ratio: 1.8848 (t-ratio:0.8945)
Schwarz Criterion: -0.429

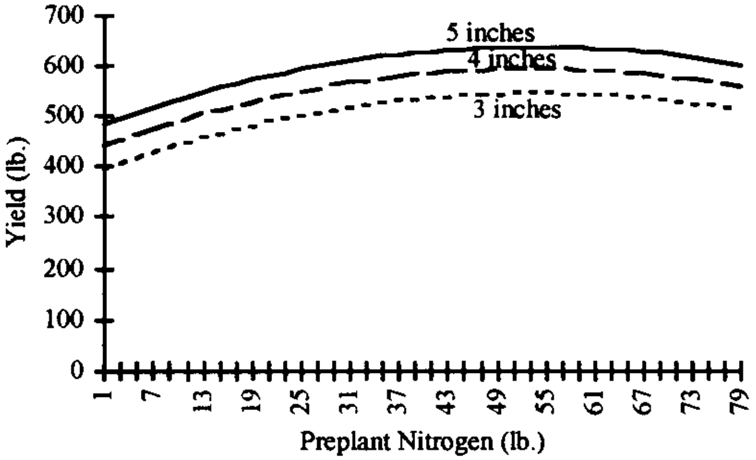
Per Acre Implications

The yield response functions and leaching functions were used to examine crop yield, net returns, and nitrate concentration of percolation for various levels of fertilizer applications under the Abilene soil. Selected relationships are presented to provide insight into the curvature of the response functions.

Yield and Returns

Figure 4.1 (upper panel) shows the relationship between yield and a preplant nitrogen application for irrigated cotton under three irrigation levels. It was assumed that the same quantity of water was applied at each of the three periods. The curve showing the highest yield is for a five inch irrigation, followed by a four inch and a three inch irrigation. The relationship is plotted for an average rainfall scenario. For five inches of irrigation, crop yield reaches the maximum at 638 lbs. with 55 lbs. of applied nitrogen. The curve is rather flat since with low water stress, nitrogen fertilizer slightly increases the yield (from 487 lbs. to 638 lbs. for a five inch irrigation). The maximum per acre yield for four and three inches of irrigation application occurs at 594 lbs. and 546 lbs., respectively. These maximum yields also occur at about 55 lbs. of nitrogen application.

Figure 4.1 (lower panel) shows the relationship between net returns (over variable cost) and preplant nitrogen for the same three irrigation levels. The maximum net returns are $183/ac., $166/ac. and $159/ac. for four inches, three inches and two inches of irrigation, respectively. The maximum net returns occur at a slightly lower fertilizer level compared to maximum crop yield (55 lbs. for maximum yield versus 51 lbs. for maximum net returns). This illustrates the concept that maximum yield for nitrogen approximates maximum profit when nitrogen costs are low.



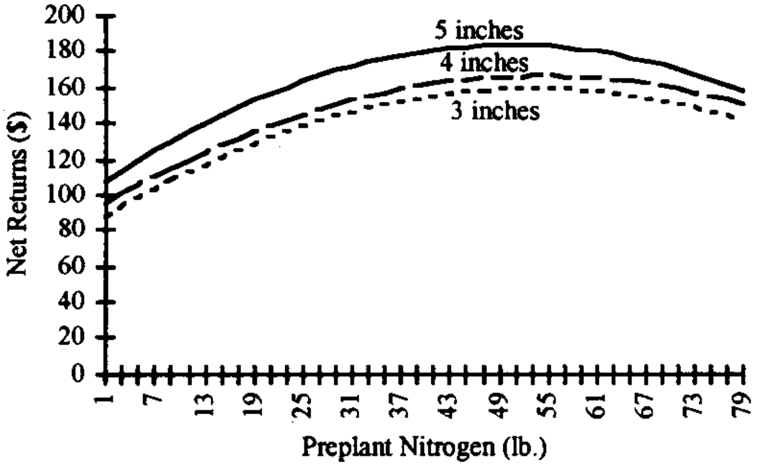


Figure 4.1. Relationship Between Yield, Net Returns, and Nitrogen for Irrigated Cotton

Figure 4.2 (top panel) shows the relationship between dryland cotton yield and preplant nitrogen application rate under an average rainfall scenario. The intercept shows that under average rainfall condition, a yield of 240 lbs. of dryland cotton would be expected without any fertilizer. With increasing nitrogen use, the dryland cotton yield reaches a maximum at 372 lbs./ac. with 41 lbs. of nitrogen. Figure 4.2 (lower panel) plots net returns (over variable cost) of dryland cotton and preplant nitrogen fertilizer. Under average rainfall condition, the net returns reach the maximum at $156/ac. with 39 lbs. of fertilizer.

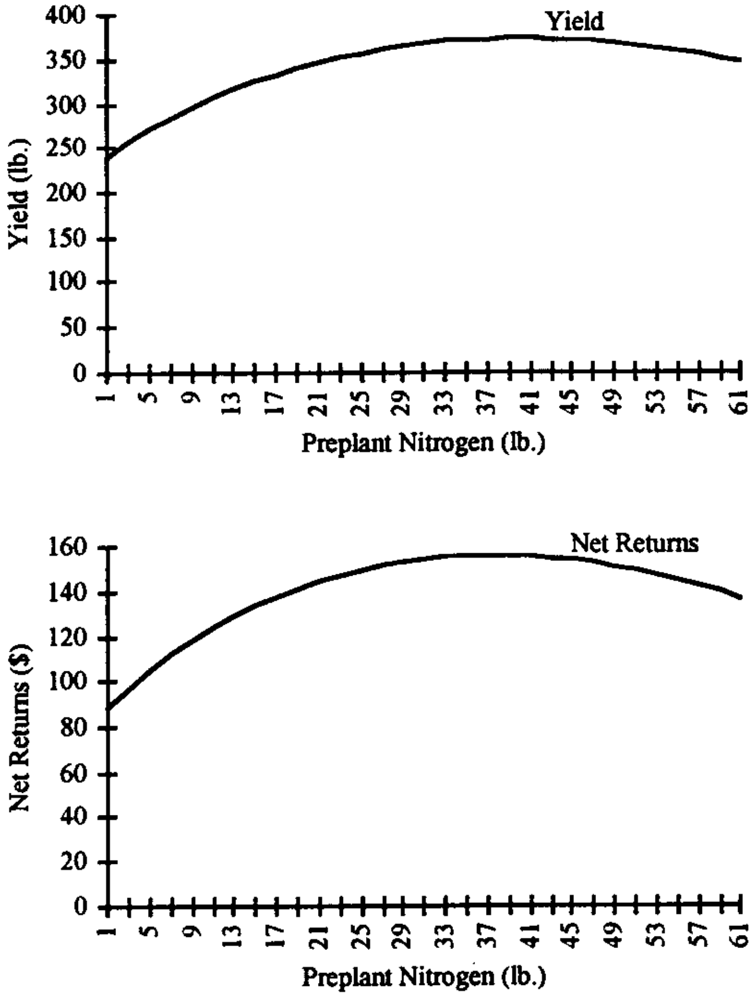


Figure 4.2. Relationship Between Yield, Net Returns, and Nitrogen for Dryland Cotton

The relationship between dryland wheat yield and preplant nitrogen is shown in Figure 4.3 (top panel). Yield reaches a maximum at 26.23 bushels with 61 lbs. of nitrogen applied. The lower panel of Figure 4.3 plots net returns and preplant nitrogen. At 53 lbs. of fertilizer use, net returns for dryland wheat are $64.17/ac. This return also includes a grazing income of $20/ac.

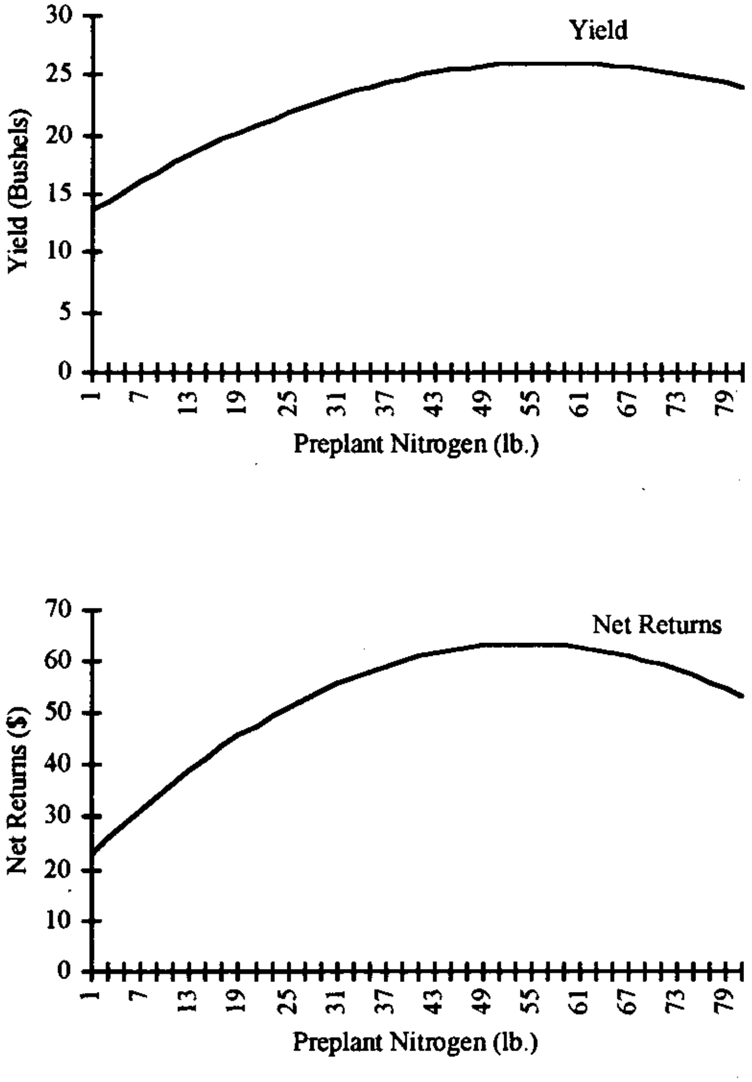


Figure 4.3. Relationship Between Yield, Net Returns, and Nitrogen for Dryland Wheat

Nitrate Percolation

Figure 4.4 shows nitrate percolation in ppm for irrigated cotton for the preplant (solid line) and split application (dashed line) of fertilizer under a three inch irrigation level in each of the three periods. It is assumed that the split fertilizer is applied with a 50-50 proportion. The concentration of nitrate percolation exceeds 10 ppm at 52 lbs. of fertilizer application. A split application of the same amount of nitrogen (26 lbs. preplant + 26 lbs. postplant) results in a nitrate percolation concentration of 7.052 ppm.

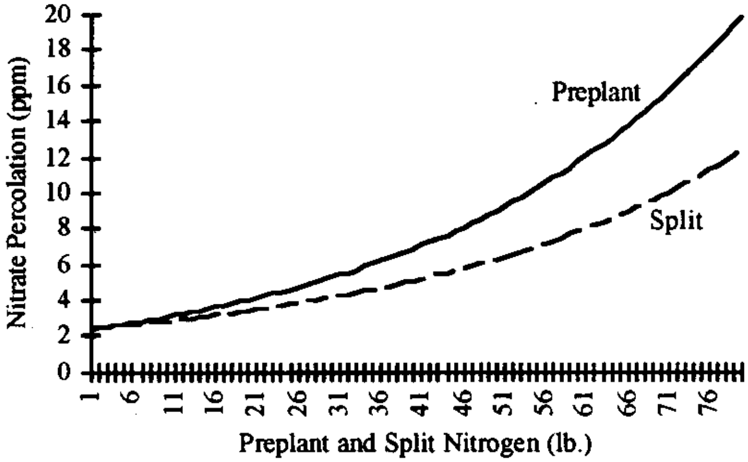


Figure 4.4. Relationship Between Nitrate Percolation and Nitrogen Application for Irrigated Cotton: Three Inches of Irrigation in Each of the Three Periods

Figure 4.5 presents the relationship between nitrate percolation and nitrogen application for a four inch irrigation level in each of the three periods. In this case, nitrate percolation exceeds the EPA standard at 48 lbs. of preplant nitrogen application. A split application (24 lbs. preplant + 24 lbs. postplant) reduces percolation to 7.18 ppm.

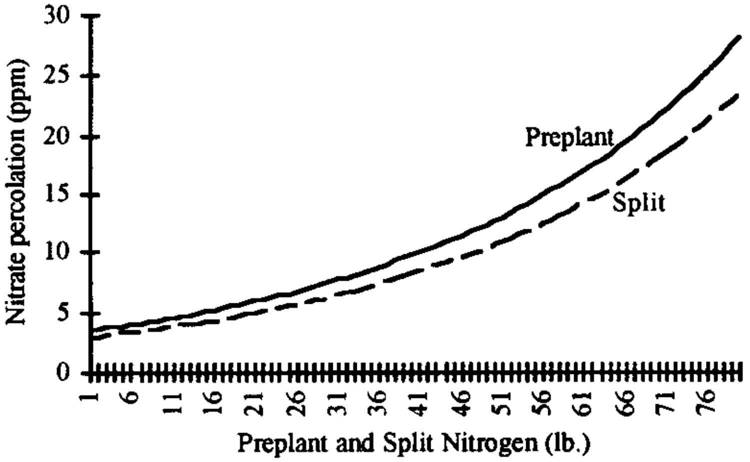


Figure 4.5. Relationship Between Nitrate Percolation and Nitrogen Application for Irrigated Cotton: Four Inches of Irrigation in Each of the Three Periods

Figure 4.6 gives the relationship between nitrate percolation and nitrogen application under a five inch irrigation in each of the three periods. Nitrate percolation exceeds the EPA standard of 10 ppm at 43 lbs. of preplant nitrogen application. The split application of fertilizer for conventional level (26 lbs. + 26 lbs.) reduces percolation to 9.56 ppm. But the extra cost of split fertilizer application ($4.50/ac.) reduces net

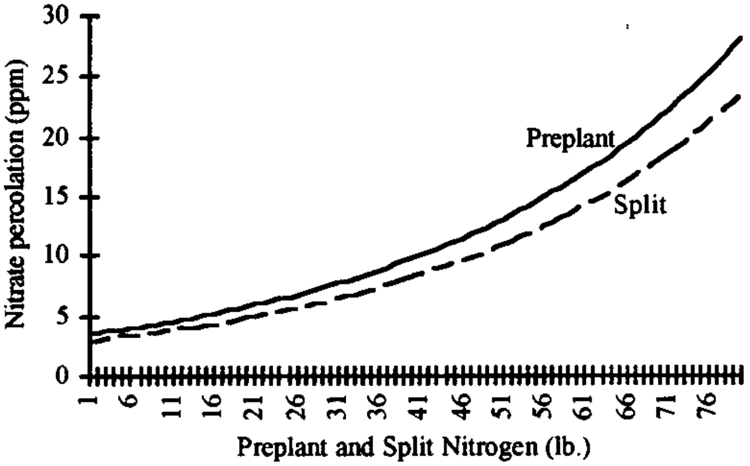


Figure 4.6. Relationship Between Percolation and Nitrogen Application for Irrigated Cotton: Five Inches of Irrigation Applied in Each of the Three Periods

returns to $178.5/ac. (a $4.50/ac. reduction). A split application of 42 lbs. (21 lbs. +21 lbs.) is estimated to decrease net returns by $8.50/ac.

The relationship between nitrate percolation concentration and nitrogen application for dryland cotton is plotted in Figure 4.7. The solid line shows percolation for a preplant application and the dashed line shows percolation for a split application. For a preplant nitrogen application, nitrate percolation exceeds 10 ppm at 23 lbs. of nitrogen application. A 40 lb. nitrogen application (conventionally used for dryland cotton), produces 21.08 ppm of nitrate percolation. A split application of the same amount of fertilizer (20 lbs. + 20 lbs.) produces 18 ppm of percolation. Compared to the irrigated cotton, profit implications for a split fertilizer application is more favorable under dryland cotton. This is because the cost of fertilizer application is slightly lower for dryland cotton ($2.15/ac. for dryland crop versus $4.50/ac. for the irrigated crop). To reduce nitrate percolation from 21.08 ppm (under a 40 lb. conventional preplant nitrogen application) to 10 ppm, preplant nitrogen use must be reduced to 23 lbs. resulting in a $8/acre reduction in net returns ($155/ac. to $147/ac.). However, with a split fertilizer application, the same nitrate percolation level (10 ppm) can be maintained with 26 lbs (13 lbs. + 13 lbs.) of fertilizer. The reduction in net returns was an estimated $5.85/ac. ($155/ac. to $149/ac.) This suggests that the split application of nitrogen fertilizer is a viable management practice for controlling nitrate concentration in the Seymour aquifer.

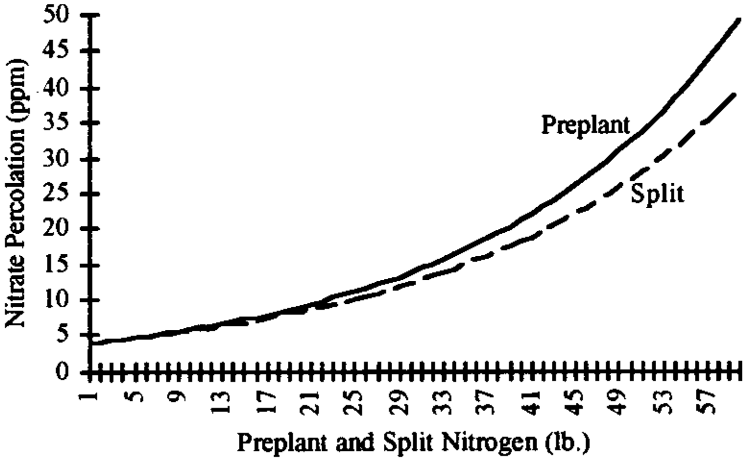


Figure 4.7. Relationship Between Nitrate Percolation and Nitrogen Application for Dryland Cotton

The per acre implications for cotton suggested that dryland cotton had more nitrate concentration (not loading) percolating to the aquifer than irrigated cotton. To investigate further the concept of nitrate concentration versus loading of dryland and irrigated cotton, the EPIC-WQ model was applied for a 25 year simulation. To investigate the sensitivity of concentration of percolation to nitrate in irrigation water, a 12 ppm of nitrates and a 50 ppm of nitrates was assumed for irrigated cotton. Further, three irrigation of 4 inches each was used for irrigated cotton along with a 50 lb. application of nitrogen fertilizer. For dryland cotton, a 40 lb. application of nitrogen fertilizer was assumed.

The EPIC-WQ simulations are presented in Table 4.9 and indicate that irrigated cotton has a higher loading of nitrates than dryland cotton even though concentration of nitrate is higher for dryland based on the 12 ppm nitrate scenario for irrigation water. With a 12 ppm nitrate concentration, 12 inches of irrigation water has about 31 lbs. of nitrogen ({27,154 gallons x 12 inches/125,000} x 12 ppm = 31.2 lb.). Application of irrigation water when the plant needs it most helps to use the nitrogen in water more

Table 4.9. Loading and Concentration from Dryland and Irrigated Cotton for 25 Simulated Years: Texas Seymour Aquifer[a]

Dryland Cotton		Irrigated Cotton (12 ppm nitrate in irrig. water)		Irrigated Cotton (50 ppm nitrate in irrig. water)	
Loading	Concentration	Loading	Concentration	Loading	Concentration
17	22	32	17	32	56
0	0	0	0	0	0
0	0	3	12	3	48
0	0	0	0	0	0
1	0.863	6	2	6	37
0	0	0	0	0	0
0	0	2	6	2	41
0	0	0	0	0	0
0	0	0	0	0	0
2	7	12	5	12	39
0	0	0	0	0	0
0	0	4	6	4	32
0	0	0	0	0	0
2	3	9	3	9	28
1	16	24	10	24	42
0	0	0	0	0	0
0	0	2	5	2	27
0	0	0	0	0	0
1	0.489	4	6	4	32
0	0	0	0	0	0
0	0	0	0	0	0
0	0	6	4	6	26
16	17	29	13	29	46
2	4	9	2	9	21
0	0	2	3	2	33

[a] assumes 40 lb. of nitrogen application for dryland and 50 lb. of nitrogen for irrigated cotton along with three 4 inch irrigation.

efficiently. Also, the crop yield for irrigated cotton is more than twice that of dryland cotton implying that the irrigated cotton plant uptake of nitrogen is substantially higher than dryland cotton. In addition, with irrigation there is simply more water available to dilute the nitrogen. Although there could be other agronomic explanations for lower concentration of nitrate percolated from irrigated cotton, these are only partial explanations. One possible explanation for higher nitrate concentration leached from dryland cotton could be that in the absence of soil moisture the crop uptake of applied nitrogen is not as high as irrigated cotton. Thus, with high rainfall, particularly other than in the growing season, the applied nitrogen percolates into the aquifer with higher nitrate concentration.

It must be noted that the nitrate concentration of 12 ppm in irrigation water can be considered as a lower bound scenario. With higher concentration of nitrate in irrigation water (which is found to be as high as 50 ppm in some parts of the region) the concentration of nitrate leached on irrigated cotton is considerably higher than dryland cotton as presented in Table 4.7. Concentration of nitrates in years of percolation was estimated to be several fold greater than dryland cotton or the 12 ppm irrigation water scenario.

Figure 4.8 plots nitrate percolation and nitrogen application for dryland wheat. Nitrate percolation exceeds 10 ppm at 35 lbs. of preplant nitrogen fertilizer. A 60 lb./ac. preplant application causes an expected 15.72 ppm of nitrate percolation. To achieve a nitrate percolation level of 10 ppm, fertilizer use would need to be reduced to 35 lbs/ac. resulting in a reduction of net returns of about $6/ac. ($62.47 to $56.67). However, a 10 ppm of nitrate percolation can be maintained with little reduction in fertilizer rate if used in split application. A 21-21 split application (42 lbs./ac. total) will reduce percolation up to 10 ppm with a reduction in net returns of only $2/ac.

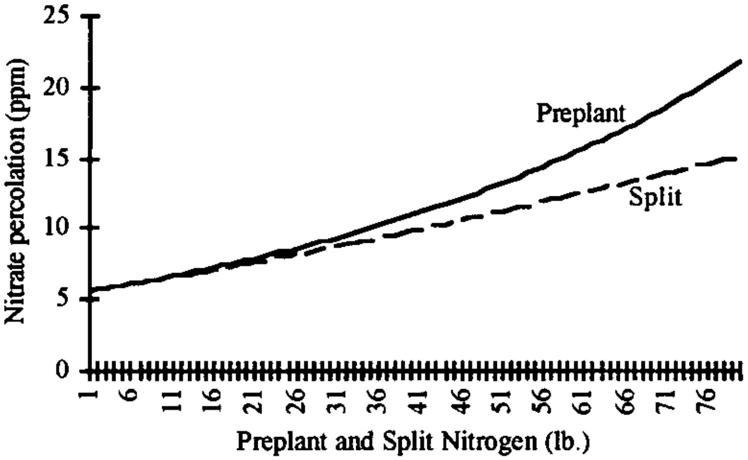


Figure 4.8. Relationship Between Nitrate Percolation and Nitrogen Application for Dryland Wheat

The general implications from the response functions are: (1) maximum net revenue is near maximum yield because of low nitrogen costs, (2) reduction in net revenue to reduce nitrate percolation to 10 ppm is relatively small on a per acre basis, and (3) often a split application of nitrogen fertilizer minimizes the reduction in net revenue to reach a 10 ppm nitrate percolation rate. This is a limited analysis and does not consider whole farm decision nor adjustment in irrigation or fertilizer across periods in a management strategy.

CHAPTER V

FARM-LEVEL RESULTS

The farm model developed for this study consists of 1,500 acres of cropland, allocated among irrigated cotton, dryland cotton, and dryland wheat. The estimated response functions for crop yield were incorporated in the model to derive baseline solutions. The nitrate leaching functions were utilized to measure the effect of environmental policy constraints on concentration of nitrogen leaching to the aquifer. A set of risk aversion coefficients were also used to examine producer behavior based on net income variability. The Abilene soil was selected for base analysis, but sensitivity to soil type was considered through the Miles soil. The following model solutions illustrate economic and environmental implications at a whole farm level for the Seymour aquifer region.

Baseline Results

The base case, representing conventional producer behavior in the Seymour aquifer area for an Abilene soil, provides a benchmark against which the effects of alternative policies can be evaluated. The base case replicates the effect of current management practices on profit in the absence of any environmental policy. A set of risk aversion coefficients (0.25 to 2.5) were used to capture the sensitivity of expected farm organization to risk.

Table 5.1 shows the mean net income, standard deviation of net income, acreage allocation, and management practices for selected levels of risk aversion. As net farm income is a function of government programs and allotments of specified crops, it discourages the diversification of farm operations. Farmers are discouraged from

Table 5.1. Estimated Mean Net Income and Farm Plan for Baseline Scenario: Texas Seymour Aquifer

R[a] A C	Mean Net Income ($)	Stn Dev ($)	Acreage	Management Practice[b]
0	154,560	23,975	Irr-Cot 334 (TP)	N1=50, N2=0, W1=5, W2=4, W3=3, T=C
			Dry-Cot 138 (MP)	N1=35, N2=0, T=C
			Dry-cot-wht-rot 406 (TP)	N1=35, N2=0, T=C
			Dry-cot-wht-rot 12 (MP)	N1=35, N2=0, T=C
			Dry-wht 425 (TP)	N1=55, N2=0, T=C
			Dry-wht 75 (MP)	N1=55, N2=0, T=C
			Set Aside 110	
0.5	154,445	23,178	Irr-Cot 334 (TP)	N1=50, N2=0, W1=5, W2=4, W3=3, T=C
			Irr-cot 84 (TP)	N1=50, N2=0, W1=5, W2=4, W3=4, T=C
			Dry-Cot 118 (MP)	N1=35, N2=0, T=C
			Dry-cot-wht-rot 322 (TP)	N1=35, N2=0, T=C
			Dry-cot-wht-rot 32 (MP)	N1=35, N2=0, T=C
			Dry-wht 425 (TP)	N1=55, N2=0, T=C
			Dry-wht 75 (MP)	N1=55, N2=0, T=C
			Set Aside 110	
2.33	152,510	22,755	Irr-Cot 27 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, T=C
			Irr-Cot 334 (TP)	N1=50, N2=0, W1=5, W2=4, W3=3, T=C
			Irr-Cot 83 (TP)	N1=50, N2=0, W1=5, W2=4, W3=4, T=C
			Dry-Cot 112 (MP)	N1=35, N2=0, T=C
			Dry-cot-wht-rot 295 (TP)	N1=35, N2=0, T=C
			Dry-cot-wht-rot 38 (MP)	N1=35, N2=0, T=C
			Dry-wht 425 (TP)	N1=55, N2=0, T=C
			Dry-wht 75 (MP)	N1=55, N2=0, T=C
			Set Aside 110	
2.50	148,385	21,440	Irr-Cot 27 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, T=C
			Irr-Cot 334 (TP)	N1=50, N2=0, W1=5, W2=4, W3=3, T=C
			Irr-Cot 83 (TP)	N1=50, N2=0, W1=5, W2=4, W3=4, T=C
			Dry-Cot 112 (MP)	N1=40, N2=0, T=C
			Dry-cot-wht-rot 295 (TP)	N1=40, N2=0, T=C
			Dry-cot-wht-rot 38 (MP)	N1=40, N2=0, T=C
			Dry-wht 425 (TP)	N1=55, N2=0, T=C
			Dry-wht 75 (MP)	N1=55, N2=0, T=C
			Set Aside 110	

Average Nitrate Percolation: 14.98 ppm

[a] Risk Aversion Coefficient

[b] N1=Preplant Nitrogen Use (lb.), N2=postplant Nitrogen Use (lb.); W1=irrigation level in period 1 (inches), W2=Irrigation level in period 2 (inches), W3=Irrigation level in period 3 (inches); T=Tillage Practice: C=Conventional, M=Minimum; TP=Target Price, MP=Market Price;

planting crops other than the base crop because every acre of base planted in another crop would reduce the size of their deficiency payment. This is reflected in the model solution where the profit-maximizing farm plan does not change between the risk aversion levels of 0.5 and 2.0. Starting at the risk aversion level of 2.33, the farmer changes the farm plan to reduce the variability of net income. Thus, in addition to the risk neutral case, the model solutions are reported only for risk aversion levels 0.5, 2.33 and 2.5.

The first row in Table 5.1 shows the optimal farm plan and profit for a risk neutral farmer with an average net income of $154,560 (standard deviation of $23,975). Net income is measured as gross income minus variable costs only. The risk neutral farmer does not use up all the irrigated acreage because with lower variable cost and higher variability, dryland cotton is competitive with irrigated cotton. A lower effectiveness of irrigation in period 3 results in only a 3 inch irrigation in this period. At a risk aversion coefficient of 0.5, the case farmer increases irrigated cotton acreage by 84 and adds more water in period 3 to this acreage. The optimal solution brings more irrigated cotton acreage (up to the limit) at the risk aversion level of 2.33 with some minor changes in dryland cotton and dryland cotton-wheat-rotation acreage. The mean income declines by about $2,000 with an associated decline in the variability of returns. At the risk aversion coefficient of 2.5, further rearrangement of the farm plan becomes impossible and the farmer changes only some management practices. Slightly higher levels of fertilizer are used for dryland cotton and dryland-cotton-wheat-rotation.

Dryland monoculture wheat acreage is constant across risk aversion levels at 500 acres. Since wheat provides grazing income, the farm program constraint (cotton cannot be grown on wheat base) leaves wheat as the best crop from a net income standpoint. Due to additional cost, post-plant nitrogen application does not enter the solution regardless of risk aversion. The slightly lower cost of minimum tillage does not outweigh the cost of a slightly lower yield leading to the use of conventional tillage in all cases. Concentration of nitrate percolation for risk neutral (RAC=0) and risk averse (RAC=2.5) was 15.48 ppm and 14.47 ppm, respectively. The concentration of nitrate percolation for the risk averse case was slightly lower as irrigated cotton had lower concentration of nitrate percolation (assuming a 12 ppm nitrate in irrigation water). The results presented in Table 5.1 provide the basis from which impacts of alternative strategies and policies are measured.

Results with Policy Constraints

Policy instruments discussed in Chapter II were incorporated in the farm-level model to examine the effect on management decisions, loss of profit for farmers and the effect on nitrogen percolation into the aquifer. The transferable permit policy was not considered for the region because of the homogeneity of polluters making trade somewhat difficult. Other policies such as water marketing is also not considered because of the absence of alternative demands across the region. The policies are also examined in a static framework ignoring transactions costs and distributional implications.

Performance Standard

Using the estimated response functions for nitrate leaching, environmental constraints were incorporated into the model where the concentration of nitrate was not allowed to exceed 10 ppm. Two emission restrictions were used: (i) a per acre constraint where concentration of leaching could not exceed 10 ppm for any acre used for cultivation, and (ii) a farm-level constraint where the total farm-level emission could not exceed 10 ppm times the number of acres cultivated. Both constraints were used to evaluate the impact on net income and expected changes in farming practices.

Table 5.2 shows the acreage allocation and management practices under a per acre performance standard. As shown previously in the base scenario, with the farm program constraints, farmer behavior shows sensitivity to risk only at higher risk aversion levels. With additional constraints such as limits on nitrate percolation, the choice set of alternative farm plans is narrower. The model solution thus showed sensitivity only at extreme levels of risk behavior (risk neutral and high risk aversion). Therefore, the model solutions are listed under two categories: risk neutral (RAC=0) and risk averse (RAC =2.5). It must also be noted that the model solution under the performance standard provided an estimate of the applicable design standards since these farm plans and management practices reduced nitrate concentration below 10 ppm. The primary change in management observed in the optimal solution is the decrease in fertilizer rate applied. Specifically, fertilizer application in dryland cotton is about 50% lower than for the baseline results. The fertilizer application rate in irrigated cotton is 10% lower implying that with minimum tillage, slightly reduced fertilizer and intensive irrigation, concentration level of percolation can be reduced to the federal standard. A split application of fertilizer is also used for wheat. Irrigation levels do not show any major change under the environmental constraints because irrigation water does not increase the concentration of leaching as much as fertilizer. Since lower irrigation has a substantial effect on yield compared to a negligible effect on the concentration of percolation, irrigation levels remained unchanged. It must be noted that the results are based on a 12 ppm nitrate concentration in irrigation water. The farm-level results under a nitrate percolation constraint are expected to change with higher concentration of nitrate in irrigation water.

Table 5.2. Estimated Mean Net Income and Farm Plan Under a Per Acre Performance Standard for Nitrate Percolation: Texas Seymour Aquifer

RISK	Mean Net Income ($)	Stn Dev ($)	Acreage	Management Practice[a]
Risk Neutral	148,340	23,740	Irr-Cot 27 (TP)	N1=45, N2=0, W1=5, W2=3, W3=4, T=M
			Irr-Cot 334 (TP)	N1=45, N2=0, W1=5, W2=4, W3=3, T=M
			Irr-Cot 84(TP)	N1=45, N2=0, W1=5, W2=4, W3=4, T=M
			Dry-Cot 112 (MP)	N1=20, N2=0, T=C
			Dry-cot-wht-rot 295 (TP)	N1=20, N2=0, T=C
			Dry-cot-wht-rot 38 (MP)	N1=20, N2=0, T=C
			Dry-wht 425 (TP)	N1=25, N2=15, T=C
			Dry-wht 75 (MP)	N1=25, N2=15, T=C
			Set Aside 110	
Risk Averse	143,160	22,195	Irr-Cot 27 (TP)	N1=45, N2=0, W1=5, W2=3, W3=4, T=M
			Irr-Cot 334 (TP)	N1=45, N2=0, W1=5, W2=4, W3=4, T=M
			Irr-Cot 84(TP)	N1=45, N2=0, W1=5, W2=4, W3=4, T=M
			Dry-Cot 112 (MP)	N1=20, N2=0, T=C
			Dry-cot-wht-rot 295 (TP)	N1=20, N2=0, T=C
			Dry-cot-wht-rot 38 (MP)	N1=20, N2=0, T=C
			Dry-wht 425 (TP)	N1=45, N2=10, T=C
			Dry-wht 75 (MP)	N1=25, N2=15, T=C
			Set Aside 110	

Average Nitrate Percolation: 9.88 ppm

[a] N1=Preplant Nitrogen Use (lb.), N2=postplant Nitrogen Use (lb.); W1=irrigation level in period 1 (inches), W2=Irrigation level in period 2 (inches), W3=Irrigation level in period 3 (inches); T=Tillage Practice: C=Conventional, M=Minimum; TP=Target Price, MP=Market Price;

Table 5.3 shows the acreage allocation and management practices under a farm-level environmental constraint. The optimal farm plan obtained under this constraint is different from the per acre constraint since the objective of the farmer is not to exceed total farm level nitrate leaching rather than a per acre nitrate leaching level. The reduction in net income under a farm-level constraint is not as high as a per acre constraint since the farm-level constraint offers more flexibility to the farmer; some acres can exceed the standard as long as other acres are sufficiently low to offset the violation. Because of more flexibility under this constraint, the reduction in nitrate percolation was accomplished through split use of fertilizer, minimum tillage in selected crops, lower fertilizer application rates and diverse acreage allocation. Split application of nitrogen

Table 5.3. Estimated Mean Net Income and Farm Plan Under a Farm-level Performance Standard for Nitrate Percolation: Texas Seymour Aquifer

RISK	Mean Income ($)	Stn Dev ($)	Acreage	Management Practice[a]
Risk Neutral	151,270	23,448	Irr-Cot 34 (TP)	N1=20, N2=30, W1=5, W2=3, W3=3, T=M
			Irr-Cot 308 (TP)	N1=20, N2=30, W1=5, W2=4, W3=3, T=M
			Irr-Cot 103	N1=20, N2=30, W1=5, W2=4, W3=4, T=M
			Dry-Cot 112 (MP)	N1=25, N2=0, T=C
			Dry-cot-wht-rot 295 (TP)	N1=25, N2=0, T=C
			Dry-cot-wht-rot 38 (MP)	N1=25, N2=0, T=C
			Dry-wht 166 (TP)	N1=30, N2=15, T=C
			Dry-wht 259 (TP)	N1=30, N2=20, T=C
			Dry-wht 75 (MP)	N1=30, N2=15, T=C
			Set Aside 110	
Risk Averse	145,345	21,756	Irr-Cot 103 (TP)	N1=20, N2=25, W1=5, W2=4, W3=4, T=M
			Irr-Cot 34 (TP)	N1=20, N2=30, W1=5, W2=3, W3=3, T=M
			Irr-Cot 308 (TP)	N1=20, N2=30, W1=5, W2=4, W3=3, T=M
			Dry-Cot 112 (MP)	N1=25, N2=0, T=C
			Dry-cot-wht-rot 295 (TP)	N1=25, N2=0, T=C
			Dry-cot-wht-rot 38 (MP)	N1=25, N2=0, T=C
			Dry-wht 14 (TP)	N1=30, N2=15, T=C
			Dry-wht 411 (TP)	N1=30, N2=20, T=C
			Dry-wht 75 (MP)	N1=25, N2=20, T=C
			Set Aside 110	

Average Nitrate Percolation: 10 ppm

[a] N1=Preplant Nitrogen Use (lb.), N2=postplant Nitrogen Use (lb.); W1=irrigation level in period 1 (inches), W2=Irrigation level in period 2 (inches), W3=Irrigation level in period 3 (inches); T=Tillage Practice: C=Conventional, M=Minimum; TP=Target Price, MP=Market Price;

fertilizer is used for dryland wheat while the minimum tillage is used under irrigated cotton in combination with split applications of fertilizer. Like the per acre constraint, lower fertilizer levels are also used for all dryland crops. Thus, the results of a farm-level environmental constraint suggests a more flexible and diversified farm plan.

Performance Tax

The objective of target emission can also be achieved with a "pricing" instrument such as a performance tax. The idea behind performance tax is to charge a fixed price for each unit of nitrate percolation. The farmer would compare the marginal benefit associated with each additional unit of nitrate percolation with the tax rate. Using the per acre nitrogen leaching constraint suggests an emissions tax ranging between $0.83 per ppm/ac. of nitrate percolation (risk neutral case) and $0.80 per ppm/ac. of nitrate percolation (risk averse). Using the base case, where the percolation level was 14.98 ppm, a tax of the above rate was imposed on every ppm of concentration of nitrate percolation.

The model solution of the performance tax is reported in Table 5.4. An appropriate performance tax imposes the same abatement cost as a standard. Thus, the optimal farm plan is similar to performance standard. The large reduction in net income, however, results from tax payments paid on every unit of nitrate percolation (amount of tax payments are reported in Table 5.13 where the cost of all policies are compared).

Performance Subsidy

An appropriately designed performance subsidy would provide the same incentive as a performance tax on the margin as the opportunity cost is the same for a subsidy and a tax, i.e., he/she can pay taxes by polluting more or can receive a subsidy by polluting less. The policies would differ, however, with respect to distribution of income and political acceptability. A performance subsidy estimated at $0.83 (risk neutral case) and $0.80 (risk averse case) per ppm of nitrate percolation was given starting at base case percolation down to 10 ppm. As Table 5.5 shows, the performance subsidy resulted in the same farm-plan as a performance tax for the risk neutral case. In the risk averse case (where the farmer prefers lower variability at the expense of lower mean income) more intensive irrigation is used on the same irrigated acres along with slightly lower fertilizer on dryland wheat. The subsidy enables the farmer to cover the extra cost of intensive irrigation. In terms of economic efficiency, an emissions subsidy on every unit of emission reduction is equally efficient as an emissions tax.

Table 5.4. Estimated Mean Net Income and Farm Plan Under a Performance Tax: Texas Seymour Aquifer

RISK	Mean Net Income	Stn Dev	Acreage	Management Practice[a]
Risk Neutral	$137,220	$24,350	Irr-Cot 27 (TP)	N1=45, N2=0, W1=5, W2=3, W3=4, T=M
			Irr-Cot 334 (TP)	N1=45, N2=0, W1=5, W2=4, W3=3, T=M
			Irr-Cot 84(TP)	N1=45, N2=0, W1=5, W2=4, W3=4, T=M
			Dry-Cot 112 (MP)	N1=20, N2=0, T=C
			Dry-cot-wht-rot 295 (TP)	N1=20, N2=0, T=C
			Dry-cot-wht-rot 38 (MP)	N1=20, N2=0, T=C
			Dry-wht 425 (TP)	N1=25, N2=15, T=C
			Dry-wht 75 (MP)	N1=25, N2=15, T=C
			Set Aside 110	
Risk Averse	$133,152	$22,050	Irr-Cot 27 (TP)	N1=45, N2=0, W1=5, W2=3, W3=4, T=M
			Irr-Cot 334 (TP)	N1=45, N2=0, W1=5, W2=4, W3=4, T=M
			Irr-Cot 84(TP)	N1=45, N2=0, W1=5, W2=4, W3=4, T=M
			Dry-Cot 112 (MP)	N1=20, N2=0, T=C
			Dry-cot-wht-rot 295 (TP)	N1=20, N2=0, T=C
			Dry-cot-wht-rot 38 (MP)	N1=20, N2=0, T=C
			Dry-wht 425 (TP)	N1=45, N2=10, T=C
			Dry-wht 75 (MP)	N1=25, N2=15, T=C
			Set Aside 110	

Average Nitrate Percolation: 9.88 ppm

Table 5.5. Estimated Mean Net Income and Farm Plan Under a Performance Subsidy: Texas Seymour Aquifer

RISK	Mean Net Income	Stn Dev	Acreage	Management Practice[a]
Risk Neutral	$155,012	$23,570	Irr-Cot 27 (TP)	N1=45, N2=0, W1=5, W2=3, W3=4, T=M
			Irr-Cot 334 (TP)	N1=45, N2=0, W1=5, W2=4, W3=3, T=M
			Irr-Cot 84(TP)	N1=45, N2=0, W1=5, W2=4, W3=4, T=M
			Dry-Cot 112 (MP)	N1=20, N2=0, T=C
			Dry-cot-wht-rot 295 (TP)	N1=20, N2=0, T=C
			Dry-cot-wht-rot 38 (MP)	N1=20, N2=0, T=C
			Dry-wht 425 (TP)	N1=25, N2=15, T=C
			Dry-wht 75 (MP)	N1=25, N2=15, T=C
			Set Aside 110	
Risk Averse	$149,169	$22,965	Irr-Cot 27 (TP)	N1=45, N2=0, W1=5, W2=4, W3=4, T=M
			Irr-Cot 334 (TP)	N1=45, N2=0, W1=5, W2=4, W3=4, T=M
			Irr-Cot 84(TP)	N1=45, N2=0, W1=5, W2=5, W3=5, T=M
			Dry-Cot 112 (MP)	N1=20, N2=0, T=C
			Dry-cot-wht-rot 295 (TP)	N1=20, N2=0, T=C
			Dry-cot-wht-rot 38 (MP)	N1=20, N2=0, T=C
			Dry-wht 425 (TP)	N1=35, N2=10, T=C
			Dry-wht 75 (MP)	N1=25, N2=15, T=C
			Set Aside 110	

Average Nitrate Percolation: 9.93 ppm

[a] N1=Preplant Nitrogen Use (lb.), N2=postplant Nitrogen Use (lb.); W1=irrigation level in period 1 (inches), W2=Irrigation level in period 2 (inches), W3=Irrigation level in period 3 (inches); T=Tillage Practice: C=Conventional, M=Minimum; TP=Target Price, MP=Market Price;

Design (Technology) Standard

Three design standards are chosen to provide some insight into the impact of mandatory design standards. The focus is on mandatory adoption of minimum tillage, mandatory split application of nitrogen fertilizer, and finally, simultaneous adoption of minimum tillage and split application of nitrogen fertilizer.

The estimated net income and farm plan under a mandatory split fertilizer application is presented in Table 5.6. The mean net income is about $5,000 lower than the base scenario because of the extra cost of a split fertilizer application and also because of the lower effectiveness of post plant nitrogen application on yield. As before, more irrigated acreage is used under the risk averse case. The mandatory split fertilizer adoption alone does not bring the percolation down substantially. The average nitrogen percolation is calculated by dividing the total nitrogen percolation for the farm by the number of acres under cultivation. While not reported in the table, under the base case, nitrogen percolation for the farm was 15.45 ppm and 14.4 ppm for risk neutral and risk averse case, respectively. Under a mandatory split fertilizer application, nitrate percolation was reduced to 13.2 ppm and 12.8 for the risk neutral and risk averse case, respectively. This suggests a mandatory requirement of split fertilizer application has limited effectiveness.

Table 5.7 reports mean net income and farm plan under a mandatory adoption of minimum tillage. The income loss is negligible as the slight yield loss under minimum tillage is offset by the reduced cost of tillage operation (some tillage operations are prohibited under minimum tillage). The reduction in nitrate percolation is also not substantial. Percolation of nitrates was reduced to 13.75 ppm (risk neutral case) and 13.16 ppm (risk averse), compared to base case of 15.46 ppm and 14.43 ppm, respectively.

To explore further the simultaneous effect of combined split application of

Table 5.6. Estimated Mean Net Income and Farm Plan Under Mandatory Split Fertilizer Application: Texas Seymour Aquifer

RISK.	Mean Income ($)	Stn Dev ($)	Acreage	Management Practice[a]
Risk Neutral	149,365	23,362	Irr-Cot 334 (TP)	N1=25, N2=35, W1=5, W2=4, W3=3, T=C
			Irr-Cot 83 (TP)	N1=25, N2=35, W1=5, W2=4, W3=4, T=C
			Dry-Cot 118 (TP)	N1=20, N2=20, T=C
			Dry-cot-wht-rot 204 (TP)	N1=20, N2=20, T=C
			Dry-cot-wht-rot 150 (MP)	N1=20, N2=20, T=C
			Dry-wht 425 (TP)	N1=30, N2=30, T=C
			Dry-wht 75 (MP)	N1=30, N2=30, T=C
			Set Aside 110	
Risk Averse	143,270	21,520	Irr-Cot 27 (TP)	N1=25, N2=35, W1=5, W2=3, W3=4, T=C
			Irr-Cot 334 (TP)	N1=25, N2=35, W1=5, W2=4, W3=3, T=C
			Irr-Cot 83 (TP)	N1=25, N2=35, W1=5, W2=4, W3=4, T=C
			Dry-Cot 112 (TP)	N1=20, N2=20, T=C
			Dry-cot-wht-rot 189 (TP)	N1=20, N2=20, T=C
			Dry-cot-wht-rot 150 (MP)	N1=20, N2=20, T=C
			Dry-wht 425 (TP)	N1=30, N2=30, T=C
			Dry-wht 75 (MP)	N1=30, N2=30, T=C
			Set Aside 110	

Average Nitrate Percolation: 13 ppm/acre

[a] N1=Preplant Nitrogen Use (lb.), N2=postplant Nitrogen Use (lb.); W1=irrigation level in period 1 (inches), W2=Irrigation level in period 2 (inches), W3=Irrigation level in period 3 (inches); T=Tillage Practice: C=Conventional, M=Minimum; TP=Target Price, MP=Market Price;

fertilizer and minimum tillage, the optimization model was solved by imposing both of these constraints (Table 5.8). The net income is slightly lower under this scenario compared to either split application or minimum tillage alone. The nitrate percolation levels under this scenario are 12.24 ppm and 11.77 ppm for risk-neutral and risk-averse case, respectively. This would suggest that although a mandatory split fertilizer application and minimum tillage reduces some nitrate percolation, these two alone cannot bring it down to the federal standard. A comprehensive design standard package must also include lower fertilizer use. However, this shows that by combining practices, there is an opportunity to reduce groundwater pollution, although there are issues on cost-effectiveness and incentives to develop and adopt new technology.

Table 5.7. Estimated Mean Net Income and Farm Plan Under Mandatory Minimum Tillage: Texas Seymour Aquifer

RISK	Mean Income ($)	Stn Dev ($)	Acreage	Management Practice[a]
Risk Neut.	153,745	24,030	Irr-Cot 334 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, T=M
			Dry-Cot 139 (TP)	N1=35, N2=0, T=M
			Dry-cot-wht-rot 267 (TP)	N1=35, N2=0, T=M
			Dry-cot-wht-rot 150 (MP)	N1=35, N2=0, T=M
			Dry-wht 425 (TP)	N1=55, N2=0, T=M
			Dry-wht 75 (MP)	N1=55, N2=0, T=M
			Set Aside 110	
Risk Averse	147,620	21,135	Irr-Cot 27 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, T=M
			Irr-Cot 334 (TP)	N1=50, N2=0, W1=5, W2=4, W3=3, T=M
			Irr-Cot 83 (TP)	N1=50, N2=0, W1=5, W2=4, W3=4, T=M
			Dry-Cot 112 (TP)	N1=35, N2=0, T=M
			Dry-cot-wht-rot 184 (TP)	N1=35, N2=0, T=M
			Dry-cot-wht-rot 150 (MP)	N1=35, N2=0, T=M
			Dry-wht 425 (TP)	N1=55, N2=0, T=M
			Dry-wht 75 (MP)	N1=55, N2=0, T=M
			Set Aside 110	

Average Nitrate Percolation: 13.45 ppm/acre

Table 5.8. Estimated Mean Net Income and Farm Plan Under Mandatory Split Fertilizer and Minimum Tillage: Texas Seymour Aquifer

RISK	Mean Income ($)	Stn Dev ($)	Acreage	Management Practice[a]
Risk Neut.	148,695	23,870	Irr-Cot 334 (TP)	N1=25, N2=25, W1=5, W2=4, W3=3, T=M
			Dry-Cot 139 (TP)	N1=20, N2=20, T=M
			Dry-cot-wht-rot 267 (TP)	N1=20, N2=20, T=M
			Dry-cot-wht-rot 150 (MP)	N1=20, N2=20, T=M
			Dry-wht 425 (TP)	N1=30, N2=30, T=M
			Dry-wht 75 (MP)	N1=30, N2=30, T=M
			Set Aside 110	
Risk Averse	142,550	21,742	Irr-Cot 27 (TP)	N1=25, N2=25, W1=5, W2=3, W3=4, T=M
			Irr-Cot 334 (TP)	N1=25, N2=25, W1=5, W2=4, W3=3, T=M
			Irr-Cot 83 (TP)	N1=25, N2=25, W1=5, W2=4, W3=4, T=M
			Dry-Cot 112 (TP)	N1=20, N2=20, T=M
			Dry-cot-wht-rot 184 (TP)	N1=20, N2=20, T=M
			Dry-cot-wht-rot 150 (MP)	N1=20, N2=20, T=M
			Dry-wht 425 (TP)	N1=30, N2=30, T=M
			Dry-wht 75 (MP)	N1=30, N2=30, T=M
			Set Aside 110	

Average Nitrate Percolation: 12.005 ppm/acre

[a] N1=Preplant Nitrogen Use (lb.), N2=postplant Nitrogen Use (lb.); W1=irrigation level in period 1 (inches), W2=Irrigation level in period 2 (inches), W3=Irrigation level in period 3 (inches); T=Tillage Practice: C=Conventional, M=Minimum; TP=Target Price, MP=Market Price;

Nitrogen Tax

An input tax is imposed on the pollution contributing input to discourage higher use. Fertilizer taxes are now in effect in Iowa, Missouri, Wisconsin, and Illinois (Ferguson, Klausner, and Reid). Iowa, for example, has a $0.75/ton tax on fertilizer. Missouri uses tax revenue to develop improved farm production practices that reduce agricultural nonpoint source pollution.

It was found in the farm-level solution that the quantity of irrigation does not affect percolation significantly. Imposing taxes on tillage, use of particular soil and/or acreage allocation is difficult from a practical standpoint. In this study, a tax on nitrogen was imposed that reduced nitrate percolation down to the EPA standard. This input tax scenario was explored realizing that it will be overly burdensome and the loss of income could not be compared with the loss of income from other policies. The loss of profit under a nitrogen tax is substantial since a farmer is forced to make huge adjustments in terms of fertilizer use only. The price of nitrogen fertilizer was parametrically increased until the total nitrate percolation into the aquifer was reduced to the EPA standard. For a risk neutral and a risk averse farmer, the tax on nitrogen was estimated at $0.60/lb. and $0.72/lb. with an income loss of $29,680 and $36,910 per year, respectively. The tax is about 200 to 250% of the purchase price of nitrogen.[11] Table 5.9 reports the profit-maximizing farm-plan under the input tax. The tax reduced fertilizer use by 30% in irrigated cotton, 29% in dryland cotton and 54% in dryland wheat. Irrigated cotton is totally eliminated under the risk neutral scenario since irrigated cotton uses more fertilizer than dryland cotton. Although dryland wheat uses more fertilizer than irrigated cotton, dryland wheat still enters the solution since a participating farmer has no choice but to grow wheat (cotton cannot be produced on

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[11] The loss of producer income and nitrate percolation under a 50%, 100%, and 150% nitrogen tax were $5,510 (with 14.3 ppm/acre), $9,850 (with 13.1 ppm/acre), and $16,290 (with 12.60 ppm/acre), respectively.

Table 5.9. Estimated Mean Net Income and Farm Plan Under a Nitrogen Tax: Texas Seymour Aquifer

RISK	Mean Income ($)	Stn Dev ($)	Acreage	Management Practice[a]
Risk Neutral	124,880	27,287	Dry-Cot 72(TP) Dry-Cot 150 (MP) Dry-cot-wht-rot 667 (TP) Dry-wht 425 (TP) Dry-wht 75 (MP) Set Aside 110	N1=25, N2=0, T=C N1=25, N2=0, T=C N1=25, N2=0, T=C N1=30, N2=0, T=C N1=25, N2=0, T=C
Risk Averse	111,475	18,794	Irr-Cot 334 (TP) Irr-Cot 83 (TP) Dry-Cot 118 (MP) Dry-cot-wht-rot 323 (TP) Dry-cot-wht-rot 32 (MP) Dry-wht 425 (TP) Dry-wht 75 (MP) Set Aside 110	N1=35, N2=0, W1=5, W2=4, W3=3, T=C N1=35, N2=0, W1=5, W2=4, W3=4, T=C N1=25, N2=0, T=C N1=30, N2=0, T=C N1=25, N2=0, T=C N1=30, N2=0, T=C N1=25, N2=0, T=C

Average Nitrate Percolation: 9.94 ppm/acre

[a] N1=Preplant Nitrogen Use (lb.), N2=postplant Nitrogen Use (lb.); W1=irrigation level in period 1 (inches), W2=Irrigation level in period 2 (inches), W3=Irrigation level in period 3 (inches); T=Tillage Practice: C=Conventional, M=Minimum; TP=Target Price, MP=Market Price;

wheat acreage according to farm program provisions). The model solution shows that the relative impact on net revenue at the farm-level could make the policy makers think twice about imposing a nitrogen tax. If the the tax is small and primarily used for revenue generation (such as in Iowa), then it will not solve the externality.

One of the problems commonly faced by the proponents of input taxes is the difficulty of quantifying the appropriate level of the input tax. During the last 15 years, fertilizer prices have fluctuated over 300% without any significant changes in use pattern (Francis). The model solution confirms the commonly held assumption that the nitrogen tax rate has to be set very high relative to the current market prices, to be effective. In addition, it may need periodic revisions in response to changes in the economic environment. The nitrogen tax will seriously affect the income of the farming community and consequently will be resisted by the agribusiness sector. It will also be difficult to determine the farming community's response to a given tax rate. An increase in fertilizer cost may initially reduce nitrogen use, but in the long run it may result in increased acreage allocated to crops in more marginal areas of production. A tax would also work as an economic punishment to individuals already using improved farming systems. An additional concern is the possible use of nitrogen fixing plants by farmers to obtain nitrogen for field crops. The percolation of nitrogen from this activity may be greater than commercial fertilizer. The effects of a nitrogen tax are thus difficult to determine.

Nitrogen Subsidy

An input subsidy is another policy option where a subsidy per lb. of nitrogen use could be given to farmers for using lower fertilizer compared to a baseline. Farmers face a similar penalty at the margin for nitrogen use. Thus, ignoring the nature of transfer payments, the impact of a nitrogen tax and nitrogen subsidy on pollution abatement is the same. An input subsidy was introduced in the model where a farmer would receive a subsidy of $0.60/lb. of nitrogen for every lb. of nitrogen used below the conventional level. Table 5.10 shows mean net income and the profit-maximizing farm plan under such a nitrogen subsidy.

Under a risk neutral case, the farm-level mean income is $159,034 with the same management plan as the nitrogen tax policy. The high input subsidy provides sufficient incentive for reducing nitrogen use. Thus, it results in the same farm plan as an input tax except that the farmer now receives the subsidy for using lower nitrogen from the baseline. The management practices are slightly different under the risk averse case (compared to a input tax) because of income effect of the subsidy combined with risk

Table 5.10. Estimated Mean Net Income and Farm Plan Under a Nitrogen Subsidy: Texas Seymour Aquifer

RISK	Mean Income ($)	Stn Dev ($)	Acreage	Management Practice[a]
Risk Neutral	159,034	23,410	Dry-Cot 72(TP) Dry-Cot 150 (MP) Dry-cot-wht-rot 667 (TP) Dry-wht 425 (TP) Dry-wht 75 (MP) Set Aside 110	N1=25, N2=0, T=C N1=25, N2=0, T=C N1=25, N2=0, T=C N1=30, N2=0, T=C N1=25, N2=0, T=C
Risk Averse	156,670	21,775	Irr-Cot 334 (TP) Irr-Cot 83 (TP) Irr-cot 27 (TP) Dry-Cot 118 (MP) Dry-cot-wht-rot 323 (TP) Dry-cot-wht-rot 32 (MP) Dry-wht 425 (TP) Dry-wht 75 (MP) Set Aside 110	N1=45, N2=0, W1=5, W2=4, W3=3, T=C N1=45, N2=0, W1=5, W2=4, W3=4, T=C N1=45. N2=0, W1=5, W2=4, W3=4, T=C N1=25, N2=0, T=C N1=30, N2=0, T=C N1=25, N2=0, T=C N1=30, N2=0, T=C N1=25, N2=0, T=C

Average Nitrate Percolation: 9.95 ppm/acre

[a] N1=Preplant Nitrogen Use (lb.), N2=postplant Nitrogen Use (lb.); W1=irrigation level in period 1 (inches), W2=Irrigation level in period 2 (inches), W3=Irrigation level in period 3 (inches); T=Tillage Practice: C=Conventional, M=Minimum; TP=Target Price, MP=Market Price;

behavior. As irrigated cotton uses slightly higher fertilizer than dryland cotton, the risk averse farmer used only a portion of potential irrigated land when a nitrogen tax was imposed (Table 5.9). With a nitrogen subsidy, however, the risk averse farmer brought all the irrigated acreage under cultivation. This is because as nitrogen is subsidized, it is now cost-effective to reduce variability of net income by using more irrigated acreage.

Lump-sum Subsidy

Lump-sum subsidies such as cost-share are payments made for reductions in nonpoint loadings. This represents an incentive (carrot) approach to induce farmers to adopt practices associated with less discharge of nutrients and or practices as well as reduce soil erosion. The results generated for performance standard could be used as a proxy for an approximate cost-share with producers. As performance standard showed to be least costly, it would give a lower bound of a lump-sum subsidy. Depending on the risk aversion level, the range of cost share was estimated to be between $3.75/ac. and $4.47/ac. These subsidies could be given for reductions in fertilizer use relative to some benchmark. Subsidies could also be given to help cover some portion of the cost of soil testing, split application of fertilizer, field scouting, adopting minimum tillage and other services.

Sensitivity to Miles Soil

The sensitivity of an alternative soil is investigated under two scenario: (i) an alternative soil (Miles) used for the whole farm, and (ii) allocation of acreage between two soils assuming that the case farm has both soil types.

Miles Soil for the Whole Farm

Table B.1 (in appendix) presents the baseline farm-level results for the Miles soil. Compared to the Abilene soil, it shows less sensitivity to risk because this particular soil has lower variability of yield. Average net income is also lower as crop yield is slightly lower under this soil. Compared to the Abilene soil, irrigation levels used are the same although the acreage allocation is different. The acreage allocation for dryland wheat and cotton are also the same with higher fertilizer being used for dryland production at higher risk levels.

The farm-level results under a per acre environmental constraint (performance standard) are reported in Table B.2. The differences compared to the Abilene soil are different acreage allocation for irrigated cotton, absence of split fertilizer application in wheat, and slightly higher fertilizer application in dryland cotton and dryland wheat, again showing the reduction in nitrate percolation for Miles as compared to Abilene soil.

Table B.3 presents the results under a farm-level environmental constraint. The acreage for irrigated cotton is different with no split fertilizer application. Also, compared to the Abilene soil, the Miles soil shows more diverse acreage allocation for dryland cotton-wheat-rotation. Finally, fertilizer application rates are slightly higher for all dryland crops for Miles soil.

Allocating Miles and Abeline Soil

Table B.4 gives the baseline results for a scenario where both soils (50% Miles and 50% Abilene) were allocated in the farm-level model. In the absence of any environmental constraint, the profit maximizing solution shows that dryland cotton is allocated to Abilene soil whereas irrigated cotton is allocated to a Miles soil. Dryland wheat is allocated to both soils.

The model solution for soil allocation scenario under a performance standard is presented in Table B.5. As discussed in the per acre analysis, dryland cotton has the highest nitrate percolation concentration. Dryland cotton does not enter the farm-level solution because of the constraint on the availability of cropland of each soil type. Dryland cotton is chosen in the model solution under farm-level performance standard where it is allocated entirely to the Abilene soil (Table B.6).

The major implications with regard to soil is that it is possible to attain a per acre percolation limit by allocating crops to different soil but only at a high cost, i. e. the reduction in net income is significant. This is because under a per acre nitrate percolation constraint, dryland cotton does not come into the farm-level solution. The solutions for a farm-level percolation constraint show that net income is slightly higher when farmers have the choice of allocating between two soils. Thus, a farmer can allocate crops with higher nitrate percolation to the Abilene soil and allocate crops with a lower percolation to the Miles soil to maximize profit under a farm-level percolation constraint. With adequate soil testing and monitoring and with appropriate incentives, farmers can be encouraged to cultivate crops (which has higher nitrate percolation, such as dryland cotton) on Miles soil.

Implications For Non participating Farmers

Although the participation rate in the government farm program is very high (about 90 - 95%), there are questions related to the long term maintenance of a farm program. Therefore, the economic and environmental implications for a non participating farmer were considered. The baseline farm-level results for a non participating farmer are presented in Table 5.11. Normalized crop prices were used in the model to calculate per acre net returns (Lee). The estimated net income (at RAC=0) for the farm is about $5,000 lower than the participating farmer. This figure is not greatly lower because a non participating farmer has the option of not producing wheat, which is not as profitable as cotton. Furthermore, a non participating farmer is not required to set aside land and can use all acres in the farm. With an increasing RAC, more irrigated cotton acreage is used because of lower variability of returns for irrigated cotton. Fertilization rates are the same as the participating scenario. Wheat is not chosen as a crop because of its relatively lower profitability. The per acre average nitrate percolation is higher than a participating farmer as the set aside acres are also used for cultivation.

The estimated net income and farm plan under a per acre performance standard for nitrate percolation is presented in Table 5.12. Fertilizer use is considerably lower and minimum tillage is used for irrigated cotton. Net income is about $11,000 lower

Table 5.11. Estimated Mean Net Income and Farm Plan for Baseline Scenario for Non participating Farmer: Texas Seymour Aquifer

R^a A C	Mean Net Income ($)	Stn Dev ($)	Acreage	Management Practice^b
0	149,130	40,492	Irr-Cot 84 Dry-Cot 290 Dry-cot-wht-rot 1126	N1=50, N2=0, W1=5, W2=3, W3=3, T=C N1=35, N2=0, T=C N1=35, N2=0, T=C
1.654	146,760	34,667	Irr-Cot 360 Dry-Cot 348 Dry-cot-wht-rot 792	N1=50, N2=0, W1=5, W2=3, W3=3, T=C N1=35, N2=0, T=C N1=35, N2=0, T=C
2.33	142,590	33,646	Irr-Cot 445 Dry-Cot 263 Dry-cot-wht-rot 792	N1=50, N2=0, W1=5, W2=4, W3=3, T=C N1=35, N2=0, T=C N1=35, N2=0, T=C
2.50	140,680	31,101	Irr-Cot 445 Dry-Cot 263 Dry-cot-wht-rot 792	N1=50, N2=0, W1=5, W2=4, W3=3, T=C N1=40, N2=0, T=C N1=40, N2=0, T=C

Average Nitrate Percolation: 16.77 ppm/acre

[a] Risk Aversion Coefficient

Table 5.12. Estimated Mean Net Income and Farm Plan Under a Per Acre Performance Standard for a Non participating Farmer: Texas Seymour Aquifer

RISK	Mean Net Income ($)	Stn Dev ($)	Acreage	Management Practice^b
Risk Neut.	143,310	40,980	Irr-Cot 84 Dry-Cot 290 Dry-cot-wht-rot 1126	N1=45, N2=0, W1=5, W2=3, W3=3,T=M N1=20, N2=0, T=C N1=20, N2=0, T=C
Risk Aver.	135,700	32,560	Irr-Cot 445 Dry-Cot 263 Dry-cot-wht-rot 792	N1=45, N2=0, W1=5, W2=3, W3=3, T=M N1=25, N2=0, T=C N1=25, N2=0, T=C

Average Nitrate Percolation: 9.79 ppm/acre

[b] N1=Preplant Nitrogen Use (lb.), N2=postplant Nitrogen Use (lb.); W1=irrigation level in period 1 (inches), W2=Irrigation level in period 2 (inches), W3=Irrigation level in period 3 (inches); T=Tillage Practice: C=Conventional, M=Minimum;

than the baseline. The impact is much greater on the non participating farmer than for the participating farmer where the net income loss under per acre standard was about $6,000. This is because of a higher nitrate percolation level for nonparticipants (no set aside) coupled with lower crop prices.

Evaluating the Aggregate Cost of Alternative Policies

The ranking of policy instruments with respect to least cost has generated a considerable literature. The findings are understandably not conclusive because of the complexity of the issue (e.g. Atkinson and Lewis, Atkinson and Tietenberg 1982, Spofford et al. 1983, Russel, Nichols). Other studies showed that whether a particular policy will be preferred to another depends on the precise nature of the instruments being compared (Coelho, Dewees, Yohe).

To provide a basis for comparison of farmer and government implications of alternative policies, the per acre implications are extrapolated to the Seymour aquifer region. Of the 274,500 acres in the Seymour aquifer area, about 218,200 acres are used for crop production . This figure was derived by subtracting pasture and rangeland acres (25,000), CRP acres (26,300), and other acres (5,000) not used for crop production (Seymour Aquifer HUA Project Annual Report). Thus, the total net income loss for the region can be measured by estimating the per acre net income loss and then multiplying by the total number of acres. It is recognized that all farms are not identical and the aggregate estimates only serve to give insight on a relative basis. The regional estimates are presented in Table 5.13.

To review the distribution of costs and/or revenue, we first consider a performance standard and a performance tax. When farms are identical (as assumed in this study), standards are generally viewed as the quantity dual of the optimal performance tax. At equal control levels (10 ppm), both strategies showed identical

Table 5.13. Regional Implications for Alternative Environmental Policies: Risk Neutral and Risk Averse Case[a]

	Risk Neutral		Risk Averse	
Policy Instrument	Change in Farm Net Income (in $1,000)[b]	Total Tax Revenue/ Govt. Subsidy Payment (in $1,000)[b]	Change in Farm Net Income (in $1,000)[b]	Total Tax Revenue/ Govt. Subsidy Payment (in $1,000)[b]
Performance Standard	(976)	0	(820)	0
Performance Tax	(2,722)	1,745	(2,391)	1,571
Performance Subsidy	71	(1,047)	123	(943)
Design Standard	(920)	0	(916)	0
Input (Nitrogen) Tax	(4,659)	3,270	(5,794)	4,345
Input (Nitrogen) Subsidy	702	(2,091)	1,300	(2,832)

[a] These figures do not include transactions costs

[b] Rounded to the nearest thousand

abatement costs ($976 thousand for risk neutral and $820 thousand for risk averse), but under a performance tax, the reduction in farmer's net returns are more ($2,722 thousand and $2,391 thousand for the two cases) due to an additional $1,746 thousand and $1,571 thousand tax payment for the risk neutral and risk averse case, respectively. Although a performance tax targets the problem more directly, costs of monitoring actual pollution would be very high. The same is true of a performance standard since standards based on actual pollution would be extremely difficult in an agricultural setting. Thus, ignoring these monitoring and enforcing costs, the only noteworthy difference between these policies is the added tax payments under a performance tax. This may lend support to the Buchanan and Tullock hypothesis that farmers would prefer a standard to a tax. Furthermore, studies show that if the correlation between cost of control and pollution contribution is high (which is true for the representative farm in this study), then it is more efficient to impose the discharge standard (e.g. Nichols).

The performance tax policy discussed above cannot be ruled out only because of the added cost it imposes on farmers. By judiciously using the redistributed tax revenues, performance taxes can be used to significantly increase environmental quality. Moreover, a performance tax type scheme can have political support if it is implemented in the form of a subsidy for reduction of nitrate percolation from a base level. Some studies show that political acceptability is known to be more important than tax revenues (e.g. Oehmke and Yao). The abatement cost from a performance subsidy is the same as a performance tax and performance standard since it provides the same incentive to control nitrate percolation at the margin. The abatement cost is recovered through the performance subsidy received and the net gain is $71 thousand to farmers. The subsidy outlay (government costs) is not as high as the tax payment made by the farmers since the subsidy is paid only on the units of percolation reduced (from the base level). The total subsidy outlay for the government for a performance subsidy policy is estimated to be $1,047 thousand for the risk neutral case and $943 thousand for the risk averse case.

Previous research has shown that a set of input taxes can provide the same pollution control as an emissions charge (Holtermann; Pfeiffer and Whittlesey; Griffin and Bromley; Stevens 1982). Input taxes are particularly attractive as actual emissions are unobservable or too costly to monitor in a cropping scenario with stochastic weather. However, an efficient input tax may vary among farms (unlike a uniform emissions charge) and must be imposed on all inputs that affect nitrate percolation. Because of these complexities, often a less-efficient but simpler regulatory instrument is proposed.

This analysis evaluated a nitrogen fertilizer tax such that the nitrate concentration of water percolating to the aquifer would be 10 ppm, the same as other policy options. Although water is also a potential candidate for such an input tax, a water tax was not considered because this research focused on the concentration of nitrate rather than loading. While water use increases loading, it also decreases the concentration of percolation. The estimated farm-level net income loss from a nitrogen tax is considerably higher than all other policies evaluated here ($4,659 thousand and $5,794 thousand for risk neutral and risk averse, respectively). This is because, first, leaching occurs from both organic and inorganic nitrogen sources. Second, other inputs may also affect nitrate percolation, although not as much as nitrogen. Thus, a relatively high tax on inorganic fertilizer is required to reduce nitrate percolation to the EPA standard. This relatively high rate of tax on nitrogen is consistent with other studies which indicate the inelastic demand for fertilizer (e.g. England, Dubgaard). Because of the high nitrogen tax applicable to all producers in the region, some farmers would be penalized irrespective of the possible nitrate percolation from their own land. A high nitrogen tax may also encourage producers to travel to another area to purchase fertilizer. Thus, such an input tax strategy would be expected to generate more opposition from the producers than a performance tax or standard (Stevens 1988).

A nitrogen subsidy policy can also be designed so that users of nitrogen fertilizer face the same economic incentive at the margin. For the same reasons mentioned above under a nitrogen tax, a relatively large nitrogen subsidy would be needed to provide an appropriate economic incentive to reduce nitrate percolation. The net gain in farm-level net returns under a nitrogen subsidy policy is $702 thousand. Although the abatement cost and subsidy for reducing nitrogen should roughly offset each other, the discrepancy occurs because of the discrete nitrogen levels used in the optimization model. A shift to the next input level produces a larger subsidy payment than abatement cost.

Although the net income loss under a arbitrarily chosen design standard is shown to be lower than the performance standard, it cannot be compared with other policies. This is because, unlike other policies where nitrate percolation reduced to the EPA standard, the nitrate percolation level under the arbitrarily chosen design standard did not reduce to the EPA standard.

The difference in farm net income and consequently in tax/subsidy payment for the risk averse case is due to the changes in the farming system (crops, tillage, irrigation etc.). A risk averse farmer uses more irrigated cotton to reduce the variability of returns. Irrigated cotton has an estimated lower nitrate concentration and higher nitrogen use than dryland cotton. The lower concentration of nitrate in irrigated cotton results from irrigation water which dilutes the percolating nitrates. One notable difference under the risk averse case is that the abatement costs under tax and subsidy policies are not the same. As shown by Baumol and Oates, this income effect asymmetry between performance tax/performance subsidy and nitrogen tax/nitrogen subsidy occurs because taxes reduce after-tax profits whereas the subsidy for not discharging pollution or for using lower fertilizer increases post-subsidy profits.

The above analysis gives an idea of the measure of cost of controlling concentration of nitrate percolation in terms of farmer's net income loss (or gain) and government revenue or outlay. The appropriate policy depends on the goals of society. A performance standard or a design standard reduces farm profit by about $1 million while a performance tax reduces farmer profit by about $2.7 million yet adds $1.7 million to government revenues. A performance subsidy results in a government outlay of about $1 million. A nitrogen tax or subsidy involves relatively large costs to either the farmer or the government. The overall implication is that there is about a $1 million annual cost to either the farm or the government to meet the EPA nitrate concentration of 10 ppm.

An efficient strategy for managing water quality must account for both the costs of reducing the pollutants and the benefits of increased quality (Ribaudo). Estimating the benefits of contamination abatement involves measuring the economic value of an environmental service. Because of problems involving nonexclusiveness, groundwater quality is not traded in regular economic markets. The economic value of groundwater quality resulting from contamination abatement must therefore be measured using something other than market prices. These valuations are difficult because of the problem of assigning a dollar value in the absence of market prices.

One of the benefits of lower nitrate concentration in groundwater is better human health. Because health care services are traded in economic markets, it may be possible to infer the value of human health resulting from high groundwater quality using health care expenditure data. Since these data are difficult to obtain, implicit market technique (utilizing surrogate prices) can be employed to infer about the cost. For example, the consumer expenditure on bottled water can be used as a proxy for their willingness to pay to avoid nitrate exposure. These inferential values can be compared to the costs of imposing a policy. It must be noted that this proxy for social cost ignores values that society may place on uncontaminated aquifers independent of current or anticipated use.

Recognizing the limitations, a "damages avoided" approach has been used to measure the cost of contamination by collecting the data on bottled water. It was mentioned earlier (page 15) that the 'cost of avoidance' literature shows that these expenditures are biased and overstates willingness-to-pay (WTP). The North Central Texas Municipal Water Authority supplies water to selected parts of Knox and Haskell Counties which includes 82 percent of the population (Moore). In addition, four towns in Knox County (Vera, Truscott, Gilliland, and Benjamin) and two towns in Haskell County (Weinert and Sagerton) do not have access to treated city water. The total number of households in these communities (1,665) was obtained from the local

Chambers of Commerce (Fitzerald). Cost and average consumption of bottled water were obtained from Jacobs Well (Scholz). According to the information provided by Jacobs Well, the average consumption of bottled water for an average household is about 15 gallons/week during summer months and about 10 gallons/week during other months. Using $0.35 for a gallon of bottled water, the total cost of bottled water for 1,665 households is estimated to be $352 thousand/year.

Consumer's surplus, or net willingness-to-pay, is the theoretically preferred measure of net economic value or net benefits (U.S. Water Resources Council; Stoll, Loomis, and Bergstrom). Estimation of consumer's surplus requires information on demand. In the absence of information on the demand curve, the expenditures on bottled water is used as a proxy for the loss of consumer surplus. The conceptual framework for estimating values is presented in Figure 5.1. Because the households in rural areas do not have access to municipal water, their willingness-to-pay for drinking water is very

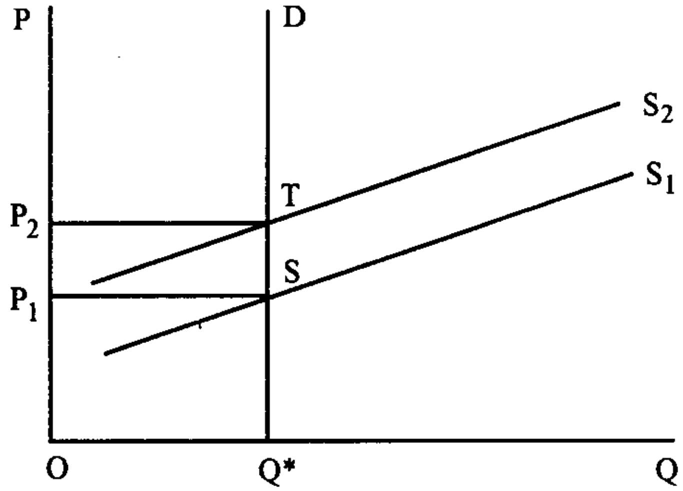

Figure 5.1. Consumer Surplus and Consumer Expenditures

high and their demand curve for drinking water is expected to be highly inelastic. For illustration, it is assumed that the demand curve (D) is completely inelastic. The supply of drinking water from the aquifer is expected to be elastic since pumping equipment is already set up and the household can pump more water than needed. Assuming some pumping cost is incurred, the household uses Q^* amount of water and pays price P_1.

If the household has to rely on bottled water because of the presence of nitrate in well water, the new supply curve of drinking water will lie to the left of the original supply curve. The price of bottled water is P_2 and the household uses the Q^* amount for drinking and cooking. The loss in consumer's surplus is P_2TSP_1. The expenditures on bottled water is P_2TQ^*O which suggests total expenditures of bottled water is an overestimate for the loss of consumer's surplus. However, P_1 (price paid for well water in the form of pumping cost) is expected to be negligible. For example, it costs about $5.20 to pump one acre inch of water or 27,154 gallons (Bevers). Assuming 12 gallons of water consumption per week per household gives 624 gallons of drinking water per household. This amount of drinking water is 2.3% of 27,154 gallons and $5.20*2.3% = $0.1196. Multiplying by the number of households and by weeks in a year gives $10,354. This figure is the expected cost of pumping household water if it was not high in nitrates and represents P_1SQ^*O in figure 5.1. This leaves added costs for bottled water of $340 thousand due to nitrates. Furthermore, other inconvenience costs associated with drinking bottled water, such as the cost of driving to the grocery store etc. are not included in the estimation.

The expenditures on bottled water (used as a proxy for the loss of consumer's surplus) can be compared to the loss of producer's surplus due to imposing a nitrogen leaching reduction policy. However, before comparing the costs of nitrate concentration control policy options to cost of bottled water, it is important to note that this comparison may not be entirely fair as the characteristics and dimensions of bottled water policy is different from the other policies. For example, the bottled water policy deals only with drinking water and ignores other values of the aquifer. Furthermore, a bottled water policy has potential slippage and it is assumed that individuals in the area are well aware of the health hazard and have easy access to bottled water.

The cost of bottled water for the region was estimated to be $340 thousand/year. The least cost alternatives for the region were about $1 million either to farmers or to the government. This cost is about two and a half to three times the cost of bottled water. When comparing the cost of bottled water to the reduction in farmer net returns, or cost to the government for a subsidy policy, the least costly way to provide "safe" household water is the use of bottled water. However, assuming pollution of the aquifer is attributable to agricultural practices, there is an opportunity for the "polluters" to compensate those impacted by the externality. For example, a small tax on nitrogen may raise enough funds to compensate the users of bottled water. Assuming 40 lbs./ac. of nitrogen fertilizer is used on average, a $0.04 tax/lb. on nitrogen fertilizer would generate approximately $349 thousand/year, which is the approximate consumer expenditures on bottled water.[12] Although this policy does not exhibit the purity of the instruments such as performance tax or tax on multiple inputs, the administration and enforcement costs are expected to be much lower. However, issues such as farmers purchasing nitrogen outside the taxed region, nonresidents taking advantage of the subsidized bottled water and the mechanism for taxing and distributing the tax dollars to residents must be given serious consideration.

The above comparison of alternative policies gives only a partial picture. Inclusion of factors such as administration costs (including information costs), enforcement costs, and political viability may dramatically change the ranking in terms

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[12] 218,200 acres * 40 lbs* 0.04 = $349,120.

of distribution and cost-effectiveness. This suggests the need for caution in recommending the cost advantages of a particular policy.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Maintaining groundwater quality and farm profitability is an important concern among the general public and within the agricultural community. Increasing health concerns for drinking water quality must be balanced with the requirements to maintain and encourage a strong sustainable agriculture. Central to the issue of groundwater quality is nitrate contamination, the most common agricultural pollutant. The Seymour aquifer of north-central Texas has been designated as a vulnerable aquifer to nitrate contamination. It is a Hydrologic Unit Area (HUA) identified in the President's Water Quality Initiative. Much of the water in the aquifer, the only source of groundwater in the area, is well above the EPA drinking water standard of 10 Parts Per Million. The most widely recognized health hazard due to nitrate exposure is clinical methemoglobinemia (blue-baby disease) in infants and gastric cancer in adults.

Managing nitrate contamination of the Seymour aquifer is a challenging task due to intensive crop production and irrigation in sandy soil, shallow depth to water level, lack of enough information, and most importantly, because of the stochastic nature of agricultural pollution. Despite these challenges, various state and federal authorities such as the Soil Conservation Service (SCS), Texas Agricultural Extension Service, Texas State Soil and Water Conservation Board, and United States Geological Survey have directed their efforts to this problem. This study attempts to contribute to their research effort by investigating the relationship between farming practices and groundwater quality for the area.

Process Model and Simulation

The lack of sufficient experimental data presents a major dilemma for research dealing with water quality. In the absence of observed data, a process model EPIC-WQ (Erosion Productivity Impact Calculator-Water Quality) was used to generate crop yield and nitrate percolation for alternative production practices. These alternative production practices include various levels of nitrogen application in different timing (preplant and postplant), alternative levels of irrigation application during three irrigation periods, soil types and tillage practices. A weather simulator inside EPIC-WQ was utilized to capture the effect of stochastic weather on yield and nitrate percolation for selected crops.

Response Functions

With many possible input combinations and management practices, the number of alternative production practices can be quite large. Thus, a set of response functions were estimated using the data from the EPIC-WQ so that the predicted value of a dependent variable can be found for any combination of inputs. Three crop yield response functions and three nitrate percolation functions were estimated using the simulated data. The crop yield functions were useful in determining the optimum input levels for reaching maximum yield and net returns. The nitrate percolation functions provided a proxy for nitrogen discharge to the aquifer on which various environmental constraints were based.

Farm-level Analysis: Baseline Results

The response functions were incorporated inside a risk-sensitive farm-level mathematical programming model developed for a case farm of the area. A set of risk aversion coefficients were also used for every scenario to see the effect of risk behavior on model optimal solution. The objective function of the model maximizes average net income (minus the risk discount) subject to the resource and environmental policy constraints. The baseline results replicates the conventional management practices for the area with acreage allocation in irrigated cotton, dryland cotton and dryland wheat. With higher risk aversion, the case farmer brings more acreage in irrigated cotton to reduce the variability of net returns at the expense of reduced average income.

Policy Implications

Various policy instruments such as a performance standard, selected design (technology) standards, a leaching tax and leaching reduction subsidy, and a nitrogen tax and nitrogen subsidy were used inside the optimization model to derive profit maximizing solutions under these constraints. Two nitrate percolation restrictions were imposed in the model as standards: (i) a per acre leaching constraint where the concentration of leaching could not exceed the EPA standard (10 ppm) for any acre used for cultivation, and (ii) a farm-level constraint where the total farm-level percolation of nitrogen could not exceed the EPA standard times the number of acres cultivated.

The imposition of a per acre environmental constraint reduced average farm net income (above variable cost) by $6,220 and $5,225 for a risk-neutral and risk-averse farmer, respectively. The reduction in percolation under a per acre percolation constraint was achieved primarily by reducing fertilizer applications. The average net income and optimal acreage allocation under a farm-level percolation constraint was different from the per acre constraint since the objective of the farmer was not to exceed the total farm level leaching rather than per acre leaching. The reduction in percolation in this case was accomplished through split use of fertilizer, minimum tillage in selected crops, lower fertilizer applications and diverse acreage allocation. The loss of average net income under a farm-level environmental constraint was $3,290 and $3,040 for the risk-neutral and risk-averse case, respectively.

The set of design standards obtained under performance standards are capable of obtaining the same level of percolation and farm income. As the study is based on a case farm, a performance standard does not have any efficiency advantage over a design standard. Planning design standards by observing nonpoint pollution is not possible in an agricultural setting and thus policy makers oftentimes arbitrarily choose design standards which are known to reduce nonpoint pollution. For example, split use of nitrogen or use of minimum tillage are known to reduce nitrogen percolation and thus are possible candidates for design standards. To examine the effect of arbitrarily chosen design standards, model solutions were derived for a minimum tillage, split nitrogen application and combined split use and minimum tillage. As expected, results show that total reduction of nitrate percolation requires a comprehensive set of design standards; arbitrarily chosen design standards only moderately reduce percolation, but not entirely up to the EPA standard.

Ignoring transactions costs and distributional implications, the same level of nitrogen percolation can be achieved either through a performance standard (a quantity instrument) or a performance tax (a price instrument). The percolation level obtained from *with* and *without* environmental constraints serve as the basis for identifying the appropriate levels of leaching/percolation tax. Using the per acre nitrogen leaching constraint solution suggests an emissions tax ranging between $0.83 per ppm and $0.80 per ppm with an income loss of $17,340 and $15,233 for risk neutral and risk averse case, respectively. The same level of emission subsidy is capable of providing the same incentive at the margin. The net gain in farm net income (subsidy received minus abatement cost) under a performance subsidy was $452 and $784 for risk neutral and risk averse case, respectively. The abatement cost and farm plan was slightly different under the risk averse case because of the income effect of subsidy payment.

Although, ideally an input tax should differ for each farm and be placed on a broad base of inputs that influence discharge, a regulatory agency may resort to a uniform tax on one input that is most closely related to the pollution problem and can be easily monitored. Thus, a tax only on nitrogen fertilizer was used in the model as nitrogen was found to be the most contributing input in the nitrate contamination problem of the aquifer. The price of nitrogen fertilizer was increased until the nitrogen percolation into the aquifer reduced to the EPA standard. This scenario was explored realizing that it will be overly burdensome and the loss of income could not be compared with the loss of income from other policies. For a risk-neutral and risk-averse farmer, the tax on nitrogen was estimated at $0.60/lb. and $0.72/lb. with a net income loss of $29,680 and $36,910, respectively. This tax is about 200 to 250% of the purchase price of nitrogen fertilizer.

An input subsidy for using lower fertilizer from the baseline can also achieve the same objective since farmers face the same penalty at the margin. For a risk neutral and risk averse farmer, the farm net income (subsidy received minus abatement cost) from an input subsidy was estimated to be $4,474 and $8,285. The risk averse case shows that because of the subsidy, all irrigated acreage is used for reducing the variability of net income.

Soil Implications

Sensitivity analysis for the Miles soil shows that the average net income would be slightly lower for the base scenario. This is because of the lower variability of yield under Miles soil. The income loss from environmental constraint is also lower in this soil type as this soil shows lower percolation than Abilene soil. The soil allocation scenario shows that dryland wheat and irrigated cotton is allocated between Miles and Abilene soil to comply with per acre performance standard. But this involves a considerable loss of income compared to the single soil analysis. The soil allocation scenario under a farm-level performance standard shows that net revenue is slightly higher when the environmental constraint is for overall farm-level percolation rather than on a per acre basis.

Aggregate (Regional) Cost

The comparison of the least costly policy instrument with the cost of bottled water suggests that in the absence of any significant non-market value of the aquifer, the region will lose about $1 million/year from the reduction in farm net income or from government subsidy outlay compared to the cost of bottled water of $340 thousand. This cost is about two and a half to three times the cost of bottled water.

Limitations of Research

The limitations of this research relate to the case-farm analysis, transactions cost of policy instruments, and dynamic and distributional implications. Perhaps the most noteworthy limitation of this research is that it is based on a case farm. The limitation of farm-level studies is that the predicted effects of a policy are conditional on the characteristics of the specific site modeled. While such efforts are useful, predictions of aggregate effects must be made with caution. More information is needed about how "representative" the results are. A related concern is the effectiveness of incentive-based policies within a single-farm framework. Incentives work best in the presence of low-cost and high-cost abators of pollution. When farms are homogeneous, incentives do not have any efficiency advantage over regulatory policies.

Transactions costs associated with various policies have been ignored in this study. Transactions cost plays a major role in the choice of an appropriate policy. A policy may seem economically sound without transactions cost, but seem too costly after considering transactions costs. For example, the private and social transactions costs of fiscal incentives may be high due to more extensive monitoring and enforcement compared to a design standard where there is lesser need for monitoring.

The distributional implications and equity or fairness concerns have not been considered in this study. For example, a subsidy increases profit, while a tax decreases them. An input tax is an income transfer from the farmers to the regulating authority whereas a standard decreases farmer's income without any income transfer. Related policy criteria that have been ignored include equity and fairness concerns. A policy where more wealthy farmers would receive a disproportionate share of government subsidy or a policy where relatively poor farmers may be burdened with a disproportionate portion of costs may violate this equity criterion.

The farm-level model used in this study is a single-period model. It only considered yield-risk and ignored price-risk. Although government farm programs substantially reduces price risk, risk may arise in the long run with high variability in market price. The crop base acreage (acres established for government program payments) of a farmer may change over time, with changes in farm-program provisions and prices. The characteristics and size of the case farm in the area may also change over time. The effectiveness of any policy instrument will thus depend on these dynamic considerations. Dynamic factors may be responsible for other indirect effects of a policy. For example, a nitrogen tax may initially reduce nitrogen fertilizer use but in the long run it may result in increased acreage allocated to crops in more marginal areas of production. This would raise the demand for farmland, benefiting existing farmland owners (Abler and Shortle).

The study is focused only on nitrate contamination. Besides nitrate, cases of pesticide contamination in selected water wells have also been identified in the area. The environmental implications of pesticide contamination must also be addressed along with nitrate contamination. Because there is some variability of nitrate concentration in the aquifer, the nitrate concentration in irrigation water also varies. In this study, a low concentration of nitrate in irrigation water (12 ppm) was used and thus policy implications are expected to vary for higher nitrate concentration in irrigation water.

The final limitation of this research relates to the accuracy and reliability of simulation models. Biophysical simulations models are continuously being improved and its results are only rough approximation of reality. A simulation model must be subjected to repeated calibration and validation before it is used for final policy analysis.

Given these limitations, the results of this research are not meant to be a recommendation. In the absence of more reliable indicators, it only serves as the "second best" measurement of the impacts of policy instruments on agricultural profit and groundwater quality. Further research that considers heterogeneous farms, transactions costs of policy, and distributional and dynamic implications is warranted.

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APPENDIX A

Table A.1. Yield and Percolation for Continuous and Dryland Cotton-Wheat Rotation: Texas Seymour Aquifer

Continuous Dryland Cotton	Dryland-Cotton-Wheat-Rotation	Continuous Dryland Cotton	Continuous Dryland Cotton	Dryland-Cotton-Wheat Rotation	Dryland-Cotton-Wheat-Rotation
Yield (lb.)	Yield (lb.)	Loading of Percolation (lb.)	Concen. of Percolation (ppm)	Loading of Percolation (lb.)	Concen. of Percolation (ppm)
404.08	409.77	17	22	16	22
394.44	391.35	0	0	0	0
321.77	319.03	0	0	0	0
337.83	340.83	0	0	0	0
392.84	383.84	1	0.863	1	0.863
278.20	283.50	0	0	0	0
344.85	337.76	0	0	0	0
340.84	337.09	0	0	0	0
424.15	424.78	0	0	0	0
407.08	413.09	2	7	3	7
447.64	447.73	0	0	0	0
341.24	346.35	0	0	0	0
322.97	329.87	0	0	0	0
458.88	456.71	2	3	1	3
363.12	361.75	1	16	1	16
297.67	301.45	0	0	0	0
399.26	402.89	0	0	0	0
394.64	391.65	0	0	0	0
280.02	282.98	1	0.489	1	0.489
295.87	295.56	0	0	0	0
390.28	389.86	0	0	0	0
487.99	487.23	0	0	0	0
488.802	493.24	16	17	15	17
264.15	266.56	2	4	1	4
304.90	298.59	0	0	0	0

A paired t-test was performed to evaluate the difference between the above distributions. Although the loadings are slightly different, concentration of percolation is exactly the same. Thus the paired t-test is performed only for the yield distributions. Formally, the paired t-test is as follows:

Null Hypothesis: $H_0 : \mu = \mu_0 \Rightarrow$ no difference between the two distributions

Alternative Hypothesis: $H_1 : \mu > \mu_0 \Rightarrow$ dryland cot-wht-rotation has higher yield

$H_1 : \mu < \mu_0 \Rightarrow$ dryland cot-wht-rotation has lower yield than monoculture (continuous) dryland cotton

Step One: Compute $t = \frac{D - \mu 0}{s/\sqrt{n}}$

Step Two: Find $t_{n-1,.05}$ and $t_{n-1,.01}$ from the t table

Step Three: using $\alpha = .05$ or $.01$, reject H_0 at the α level of significance if:

$t \geq t_{n-1,}\, \alpha$ (for $H_1 : \mu > \mu_0$)

or $t \leq t_{n-1,}\, \alpha$ (for $H_1 : \mu < \mu_0$)

$D = \Sigma D_i/25 = -9.64/25 = -0.39$

$s^2 = 25\ \Sigma D_i - (\Sigma D_i)^2 = 25(452.803)\text{-}93.01/25(24) = 8635.11$

$s = \sqrt{(8635.11)} = 92.9253$

$t = -0.021$

Critical $t_{24,\,.05} = 2.064$ and $t_{24,\,.01} = 2.797$

Thus, we cannot reject the null hypothesis i.e. there is no significant difference between the two distributions of yield.

Reference: Goldman, Robert N. and Joel S. Weinberg, *Statistics: An Introduction*. Prantice-Hall, Inc., Englewood Cliffs, New Jersey, 1985.

APPENDIX B

Table B.1. Estimated Mean Net Income and Farm Plan for Base Scenario: Miles Soil.

RISK	Mean Net Income ($)	Stn Dev ($)	Acreage	Management Practice[a]
Risk Neutral	146,600	23,922	Irr-Cot 88 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, T=C
			Irr-Cot 88 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, T=C
			Irr-Cot 269 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, T=C
			Dry-Cot 112 (MP)	N1=35, N2=0, T=C
			Dry-cot-wht-rot 295 (TP)	N1=35, N2=0, T=C
			Dry-cot-wht-rot 38 (MP)	N1=35, N2=0, T=C
			Dry-wht 425 (TP)	N1=55, N2=0, T=C
			Dry-wht 75 (MP)	N1=55, N2=0, T=C
			Set Aside 110	
Risk Averse	145,130	23,743	Irr-Cot 88 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, T=C
			Irr-Cot 88 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, T=C
			Irr-Cot 269 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, T=C
			Dry-Cot 112 (MP)	N1=40, N2=0, T=C
			Dry-cot-wht-rot 295 (TP)	N1=40, N2=0, T=C
			Dry-cot-wht-rot 38 (MP)	N1=40, N2=0, T=C
			Dry-wht 425 (TP)	N1=55, N2=0, T=C
			Dry-wht 75 (MP)	N1=55, N2=0, T=C
			Set Aside 110	

Average Nitrate Percolation: 14.2 ppm/acre

[a] N1=Preplant Nitrogen Use (lb.), N2=postplant Nitrogen Use (lb.); W1=irrigation level in period 1 (inches), W2=Irrigation level in period 2 (inches), W3=Irrigation level in period 3 (inches); T=Tillage Practice: C=Conventional, M=Minimum; TP=Target Price, MP=Market Price;

Table B.2. Estimated Mean Net Income and Farm Plan Under a Per Acre Performance Standard for Nitrate Percolation: Miles Soil.

RISK	Mean Net Income ($)	Stn Dev ($)	Acreage	Management Practice[a]
Risk Neutral	144,800	24,220	Irr-Cot 88 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, T=C
			Irr-Cot 88 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, T=C
			Irr-Cot 269 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, T=C
			Dry-Cot 112 (MP)	N1=25, N2=0, T=C
			Dry-cot-wht-rot 295 (TP)	N1=25, N2=0, T=C
			Dry-cot-wht-rot 38 (MP)	N1=25, N2=0, T=C
			Dry-wht 425 (TP)	N1=45, N2=0, T=C
			Dry-wht 75 (MP)	N1=45, N2=0, T=C
			Set Aside 110	
Risk Averse	139,140	22,537	Irr-Cot 88 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, T=C
			Irr-Cot 88 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, T=C
			Irr-Cot 269 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, T=C
			Dry-Cot 112 (MP)	N1=30, N2=0, T=C
			Dry-cot-wht-rot 295 (TP)	N1=30, N2=0, T=C
			Dry-cot-wht-rot 38 (MP)	N1=30, N2=0, T=C
			Dry-wht 425 (TP)	N1=45, N2=10, T=C
			Dry-wht 75 (MP)	N1=45, N2=10, T=C
			Set Aside 110	

Average Nitrate Percolation: 9.91 ppm/acre

[a] N1=Preplant Nitrogen Use (lb.), N2=postplant Nitrogen Use (lb.); W1=irrigation level in period 1 (inches), W2=Irrigation level in period 2 (inches), W3=Irrigation level in period 3 (inches); T=Tillage Practice: C=Conventional, M=Minimum; TP=Target Price, MP=Market Price;

Table B.3. Estimated Mean Net Income and Farm Plan Under a Farm-level Performance Standard for Nitrate Percolation: Miles Soil.

RISK	Mean Income ($)	Stn Dev ($)	Acreage	Management Practice[a]
Risk Neutral	145,170	23,980	Irr-Cot 88 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, T=M
			Irr-Cot 88 (TP)	N1=50, N2=0, W1=5, W2=4, W3=3, T=M
			Irr-Cot 269 (TP)	N1=50, N2=0, W1=5, W2=4, W3=4, T=M
			Dry-Cot 112 (TP)	N1=30, N2=0, T=C
			Dry-cot-wht-rot 36 (TP)	N1=30, N2=0, T=C
			Dry-cot-wht-rot 148 (TP)	N1=35, N2=0, T=C
			Dry-cot-wht-rot 150 (MP)	N1=30, N2=0, T=C
			Dry-wht 425 (TP)	N1=40, N2=15, T=C
			Dry-wht 75 (MP)	N1=40, N2=15, T=C
			Set Aside 110	
Risk Averse	141,780	22,406	Irr-Cot 88 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, T=M
			Irr-Cot 88 (TP)	N1=50, N2=0, W1=5, W2=4, W3=3, T=M
			Irr-Cot 269 (TP)	N1=50, N2=0, W1=5, W2=4, W3=4, T=M
			Dry-Cot 112 (MP)	N1=30, N2=0, T=C
			Dry-cot-wht-rot 102 (TP)	N1=30, N2=0, T=C
			Dry-cot-wht-rot 192 (TP)	N1=35, N2=0, T=C
			Dry-cot-wht-rot 38 (MP)	N1=30, N2=0, T=C
			Dry-wht 425 (TP)	N1=35, N2=20,T=C
			Dry-wht 75 (MP)	N1=35, N2=20,T=C
			Set Aside 110	

Average Nitrate Percolation: 10 ppm/acre

[a] N1=Preplant Nitrogen Use (lb.), N2=postplant Nitrogen Use (lb.); W1=irrigation level in period 1 (inches), W2=Irrigation level in period 2 (inches), W3=Irrigation level in period 3 (inches); T=Tillage Practice: C=Conventional, M=Minimum; TP=Target Price, MP=Market Price;

Table B.4. Estimated Mean Net Income and Farm Plan for Baseline Scenario: Allocation of Soil.

RISK	Mean Net Income ($)	Stn Dev ($)	Acreage	Management Practice[a]
Risk Neutral	154,630	23,198	Irr-Cot 88 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, S=M, T=C
			Irr-Cot 88 (TP)	N1=50, N2=0, W1=5, W2=3, W3=3, S=M, T=C
			Irr-Cot 269 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, S=M, T=C
			Dry-Cot 112 (TP)	N1=35, N2=0, S=A, T=C
			Dry-cot-wht-rot 183 (TP)	N1=35, N2=0, S=A, T=C
			Dry-cot-wht-rot 150 (MP)	N1=35, N2=0, S=A, T=C
			Dry-wht 175 (TP)	N1=55, N2=0, S=M, T=C
			Dry-wht 250 (TP)	N1=55, N2=0, S=A, T=C
			Dry-wht 75 (MP)	N1=55, N2=0, S=M, T=C
			Set Aside 110	
Risk Averse	152,760	22,807	Irr-Cot 88 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, S=M, T=C
			Irr-Cot 88 (TP)	N1=50, N2=0, W1=5, W2=3, W3=3, S=M, T=C
			Irr-Cot 269 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, S=M, T=C
			Dry-Cot 112 (TP)	N1=40, N2=0, S=A, T=C
			Dry-cot-wht-rot 183 (TP)	N1=40, N2=0, S=A, T=C
			Dry-cot-wht-rot 150 (MP)	N1=40, N2=0, S=A, T=C
			Dry-wht 175 (TP)	N1=55, N2=0, S=M, T=C
			Dry-wht 250 (TP)	N1=55, N2=0, S=A, T=C
			Dry-wht 75 (MP)	N1=55, N2=0, S=M, T=C
			Set Aside 110	

Average Nitrate Percolation: 14.7 ppm/acre

[a] N1=Preplant Nitrogen Use (lb.), N2=postplant Nitrogen Use (lb.); W1=irrigation level in period 1 (inches), W2=Irrigation level in period 2 (inches), W3=Irrigation level in period 3 (inches); S=Soil type: M=Miles, A=Abilene; T=Tillage Practice: C=Conventional, M=Minimum; TP=Target Price, MP=Market Price;

Table B.5. Estimated Mean Net Income and Farm Plan Under a Per Acre Performance Standard for Nitrate Percolation: Allocation of Soil.

RISK	Mean Net Income ($)	Stn Dev ($)	Acreage	Management Practice[a]
Risk Neutral	112,490	13,910	Irr-Cot 27 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, S=M, T=C
			Irr-Cot 334 (TP)	N1=50, N2=0, W1=5, W2=3, W3=3, S=A, T=M
			Irr-Cot 84 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, S=M, T=C
			Dry-wht 150 (TP)	N1=45, N2=10, S=A, T=C
			Dry-wht 425 (TP)	N1=45, N2=10, S=M, T=C
			Dry-wht 211 (MP)	N1=30, N2=0, S=A, T=C
			Dry-wht 159 (MP)	N1=45, N2=10, S=M, T=C
			Set Aside 110	
Risk Averse	108,640	12,456	Irr-Cot 27 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, S=M, T=C
			Irr-Cot 334 (TP)	N1=50, N2=0, W1=5, W2=3, W3=3, S=A, T=M
			Irr-Cot 84 (TP)	N1=50, N2=0, W1=5, W2=3, W3=4, S=M, T=C
			Dry-wht 150 (TP)	N1=50, N2=10, S=A, T=C
			Dry-wht 425 (TP)	N1=50, N2=10, S=M, T=C
			Dry-wht 211 (MP)	N1=30, N2=0, S=A, T=C
			Dry-wht 159 (MP)	N1=50, N2=10, S=M, T=C
			Set Aside 110	

Average Nitrate Percolation: 9.81 ppm/acre

[a] N1=Preplant Nitrogen Use (lb.), N2=postplant Nitrogen Use (lb.); W1=irrigation level in period 1 (inches), W2=Irrigation level in period 2 (inches), W3=Irrigation level in period 3 (inches); S=Soil type: M=Miles, A=Abilene; T=Tillage Practice: C=Conventional, M=Minimum; TP=Target Price, MP=Market Price;

Table B.6. Estimated Mean Net Income and Farm Plan Under a Farm-level Performance Standard for Nitrate Percolation: Allocation of Soil.

RISK	Mean Net Income ($)	Stn Dev ($)	Acreage	Management Practice[a]
Risk Neutral	152,730	23,336	Irr-Cot 77 (TP)	N1=30, N2=15, W1=5,W2=3, W3=4, S=M, T=M
			Irr-Cot 88 (TP)	N1=30, N2=15,W1=5, W2=4, W3=3, S=M, T=M
			Irr-Cot 269 (TP)	N1=30, N2=15, W1=5, W2=4, W3=4, S=M, T=M
			Irr-Cot 11 (TP)	N1=30, N2=20, W1=5, W2=3, W3=4, S=M, T=M
			Dry-Cot 111 (TP)	N1=30, N2=0, S=A, T=C
			Dry-cot-wht-rot 183 (TP)	N1=30, N2=0, S=A, T=C
			Dry-cot-wht-rot 150 (MP)	N1=30, N2=0, S=A, T=C
			Dry-wht 250 (TP)	N1=30, N2=15, S=A, T=C
			Dry-wht 175 (TP)	N1=30, N2=20, S=M, T=C
			Dry-wht 75 (MP)	N1=30, N2=20, S=M, T=C
			Set Aside 110	
Risk Averse	146,900	21,632	Irr-Cot 88 (TP)	N1=30, N2=15, W1=5,W2=3, W3=4, S=M, T=M
			Irr-Cot 88 (TP)	N1=30, N2=15,W1=5, W2=4, W3=3, S=M, T=M
			Irr-Cot 269 (TP)	N1=30, N2=15, W1=5, W2=4, W3=4, S=M, T=M
			Dry-Cot 111 (TP)	N1=30, N2=0, S=A, T=C
			Dry-cot-wht-rot 183 (TP)	N1=30, N2=0, S=A, T=C
			Dry-cot-wht-rot 150 (MP)	N1=30, N2=0, S=A, T=C
			Dry-wht 239 (TP)	N1=30, N2=15, S=A, T=C
			Dry-wht 175 (TP)	N1=30, N2=20, S=M, T=C
			Dry-wht 11 (TP)	N1=30, N2=20, S=A, T=C
			Dry-wht 75 (MP)	N1=30, N2=20, S=M, T=C
			Set Aside 110	

Average Nitrate Percolation: 10 ppm/acre

[a] N1=Preplant Nitrogen Use (lb.), N2=postplant Nitrogen Use (lb.); W1=irrigation level in period 1 (inches), W2=Irrigation level in period 2 (inches), W3=Irrigation level in period 3 (inches); S=Soil type: M=Miles, A=Abilene; T=Tillage Practice: C=Conventional, M=Minimum; TP=Target Price, MP=Market Price;

VITA

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