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ESTIMATED EFFECT OF ALTERNATIVE PRODUCTION PRACTICES ON PROFIT AND GROUND WATER QUALITY: TEXAS SEYMOUR AQUIFER

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Abstract. *The Seymour aquifer of north-central Texas is identified as containing elevated levels of nitrate. The area has been designated as a Hydrologic Unit Area under the President's Water Quality Initiative. The effect of alternative production practices on the relative changes in nitrate leaching through the vadose zone was measured by adding an extended soil profile in the EPIC-WQ simulation model. Net returns from alternative production methods were estimated by using returns from associated yield and adjusting the cost of different levels of nitrogen, irrigation, and harvesting. Tradeoffs between nitrate percolation and net returns were explored by plotting the net returns-percolation data points for various methods of production. The results indicate that the relationship between nitrate percolation and net returns is not strictly positive for all production methods; potential remains where a lower percolation level could be achieved without a significant reduction in farmer's profit.*

Since the passage of the Clean Water Act in 1972, a major focus of U.S. policy and regulation has been directed to water quality. Initially, point-source contamination of the nation's waters, such as municipalities and manufacturing plants, were addressed because they were easy to identify. The greatest initial improvement in water quality could be realized by addressing these point-sources. Regulations were enacted and economic incentives were offered to help control contamination.

Non-point contamination of U.S. waters were directly addressed with the Food Security Act of 1985, but the 1985 Farm Bill emphasized "on site" provisions—how conservation compliance would benefit the productivity of the individual farmer. Two years later, the Clean Water Act of 1987 reflected changes in legislative perception as support of nonpoint-source contamination increased; Section 208 required states to develop nonpoint-source plans. Still, the act has not resulted in significant water quality improvements, possibly due to poor coordination between federal and stage agencies.

The President's Water Quality Initiative of 1988, intended to direct attention to water quality and agriculture, recognized the importance of a team approach by federal, state, and local agencies (Lacewell et al. 1992). It resulted in a multi-agency program under the leadership of the U.S. Department of Agriculture designed to provide farmers with the knowledge and technical means to respond independently and voluntarily to on- and off-farm environmental issues and related state water quality requirements. Through this program, agricultural agencies were to define and demonstrate "best management practices" (BMPs) to maintain farm economic viability and reduce nonpoint-source water pollution. Certain water quality sensitive areas were selected 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 the local, state, and federal agencies.

The efforts of the EPA under the Clean Water Act are expected to target nonpoint-sources of water pollution, particularly after reauthorization of the Clean Water Act in 1993-94. The 1990 Farm Bill also instituted an agricultural Water Quality Protection program, which allows for cost sharing, technical assistance, and direct payments for taking susceptible land out of production.

The limited success of nonpoint-source contamination control seems largely due to a poor understanding of the relationships between agricultural production practices and water quality. To better understand this relationship, the cause and effect of agricultural water pollution must be established for different production regions. Only then can we formulate effective policy to address the issue of non-point source contamination control.

The deterioration of water quality from agricultural nonpoint-sources (NPS) basically results from four causes:

(1) soil erosion causing sediment deposition off the field of origin
(2) fertilizer and pesticide runoff flowing into surface water courses

(3) fertilizer, nutrients, and pesticides leaching into the groundwater
(4) volatilization losses at the time of application

The most common agricultural chemical pollutant is nitrogen in the form of nitrates. Growing evidence in the U.S. and abroad indicates a strong positive correlation between increase in nitrogen fertilizer use and an increased nitrate level in shallow groundwater (Hallberg 1986; Schepers et al. 1991). This raises questions about the fate and efficiency of nitrogen fertilizer for current farming practices.

Elevated nitrate levels in groundwater are attributed to the low relative cost of nitrogen fertilizers and the ease with which nitrate moves in soil. Plant nutrient use in the U.S. nearly tripled between 1960 and 1981; both total and per acre nitrogen fertilizer application increased substantially. 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 1990). As a result, the amount of nutrients in surface and groundwater increased (Miranowski 1990). While few cases of death or severe illness in adults are linked directly to nitrate, the most widely recognized human health consequence of nitrate exposure is methemoglobinemia (blue-baby disease) in infants (Bouwer 1978). Nitrate-nitrogen ($N0_3$-N) levels greater than 10 parts per million (ppm) make infants more susceptible to this disease. In irrigation water, excess nitrogen may delay harvest times and adversely affect yield and quality of citrus and other nitrogen-sensitive crops (Food and Agricultural Organization of the United Nations 1985). In addition, the potential for surface water pollution from groundwater is an important environmental concern; approximately 30% of surface water stream flow is from groundwater sources (Saliba 1985).

This paper focuses on the third process of nonpoint-source pollution—fertilizer, nutrients, and pesticides leaching into the groundwater. The Seymour aquifer (Fig. 1) of north-central Texas, designated as a Hydrologic Unit Area under the President's Water Quality Initiative, provides an ideal study area. Using a crop growth simulation model, this study measures the effect on farmer profit and the *relative* changes in groundwater quality from alternative rates of nitrogen use on cotton and wheat. Special attention is given to nitrogen management because nitrate is more likely than most pesticides to leach under normal soil and agricultural conditions. In addition, the impact of the Conservation Reserve Program (CRP) and natural sources of nitrogen release on water quality have been addressed. Finally, the paper investigates tradeoffs between farmers' average net returns and nitrogen percolation by conducting a partial budgeting analysis.

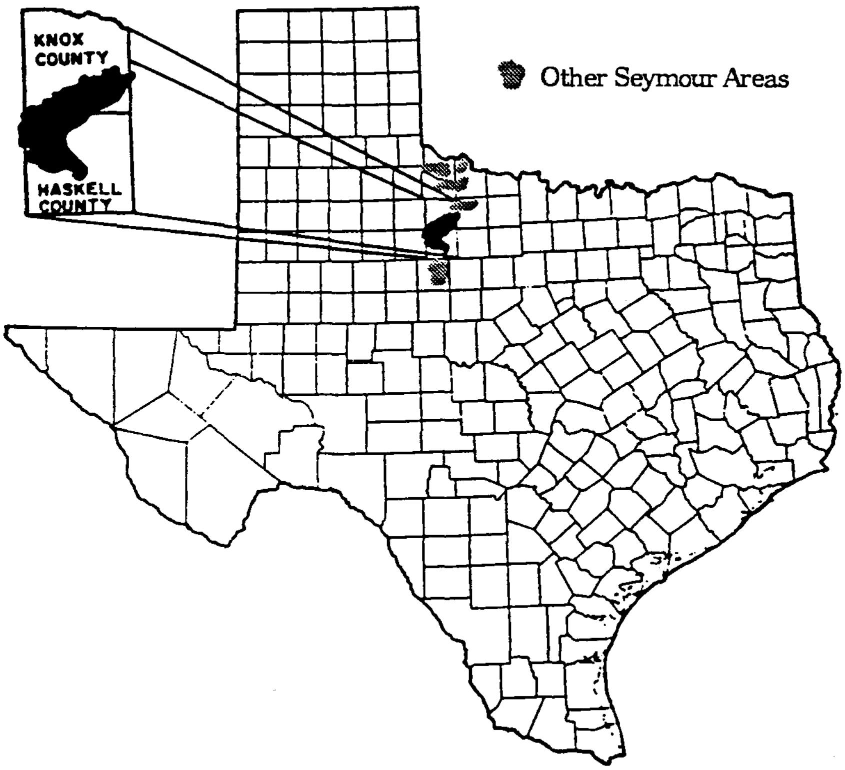

Figure 1. The Seymour aquifer (Harden and Associates 1978).

This study did not include alternative tillage practices, crop rotations, or a whole farm analysis. Therefore, these results and interpretations are to be viewed as preliminary and demonstrative of the types of analyses needed. One example of this limitation is the per acre implications for irrigated cotton. In this region water is a limiting resource and pumping capacity is not sufficient to irrigate all acres. Therefore, analysis based only on per acre results does not consider overall farm implications where much of the cropland will be farmed dryland.

Study Area

The Texas State Soil and Water Conservation Board (TSSWCB), through the Section 319 agricultural and silvicultural nonpoint pollution process, 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. It has been designated as a Hydrologic Unit Area to accelerate the adoption of best management practices to minimize pollution of the aquifer.

Regional Description

The Seymour Formation, composed of stream-deposited Pleistocene sands and gravels, is situated midway between Wichita Falls and Lubbock in north-central Texas. The region has been dissected by quaternary river valley erosion to form a series of discontinuous "plateaus." These erosional remnants function as shallow, unconfined alluvial aquifers known collectively as the Seymour aquifer and serve as the main or sole source of water in this 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 focuses on the latter segment, which represents a single hydrologic unit of the Seymour aquifer covering approximately 274,500 acres or 430 square miles (Fig. 1). The aquifer is generally composed of discontinuous beds of poorly sorted gravel, conglomerate, sand, silty clay, and caliche (Price 1979). Individual areas vary greatly in thickness, with a total thickness usually less than 100 feet (Texas Department of Water Resources 1984). The aquifer provides 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 1989). The depth to groundwater varies from 4 to 55 feet but averages 23 feet. There are over 2,000 irrigation wells, each typically yielding 200-400 gallons per minute (gpm).

An estimated 265,000 acres (97%) of the approximately 274,500 acres comprising this part of the Seymour Foundation are used for farming and ranching. Cotton (irrigated and dryland), dryland wheat, sorghum (irrigated

and dryland), and irrigated peanuts are the major crops. This study examines irrigated and dryland cotton and dryland wheat that account for 85% of the total acres of crops produced in the area (Seymour Aquifer Hydrologic Unit Project Annual Report 1991).

The soils for this study are in the Miles-Rotan association (Soil Survey of Haskell County, TX 1979; Soil Survey of Knox County, TX 1979). These are deep, nearly level (less than 1% slopes), loamy soils formed in old alluvium with a composition of about 48% Miles soils, 16% Rotan soils, and 36% minor soils. Previous studies on Knox County (Onken et al. 1977; Onken et al. 1979; Wendt et al. 1977) also used the Miles fine sandy loam soil (Udic Paleustalfs).

The Seymour aquifer's dominant source of recharge is through direct soil infiltration of precipitation 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)—a region characterized by deep, sandy soils. The Brazos River and Lake Creek are the primary surface streams adjoining the aquifer, 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 1989).

The region has a warm-temperate, subtropical climate with dry winters and hot summers. Tropical air masses have a dominant effect on area weather from April to 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. Much of the warm-season rainfall results from convective showers and thunderstorms. The average daily maximum temperature in July is 97.7° F and the average frost-free period is 219 days (Seymour Aquifer Hydrologic Unit Project Annual Report 1991).

Aquifer Water Quality

Neilson and Lee (1987) synthesized national data to identify regions affected by agricultural pesticide and fertilizer contamination. Researchers identified portions of the Texas Rolling Plains, which include the Seymour aquifer, as having high potential for nitrate-nitrogen contamination. The area contained elevated levels of nitrate in groundwater as early as 1948 (George and Hastings 1951). George and Hastings reported that about 3,000 of a total of 20,000 water wells checked in Texas prior to 1948 contained over 4.5 ppm

NO_3-N with many over 400 ppm. These samples were taken prior to the widespread use of commercial fertilizers and, as a result, nitrate occurrence appeared to be unrelated to rainfall, geography, or cultivation. The nitrate-nitrogen content of 62 water samples collected from the Seymour formation in 1962 varied from 5-41 ppm with 39 exceeding the recommended Department of Health limit of 10 ppm (Ogilbee and Osborne 1962). Nine rural communities use water from this formation and none have an approved water supply due to the presence of nitrate. Recent studies (Kreitler 1979; Harden and Associates 1978; Aurelius 1989) have shown that much of the water in the Seymour aquifer, the only groundwater source in the area, is well above the EPA drinking water standard of 10 ppm. Researchers have also identified cases of pesticide contamination in selected water wells (Aurelius 1989).

The problem of excessive nitrate has been attributed to 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 waste, and commercial fertilization used for agricultural production. A significant rise in the nitrate level of the Seymour aquifer occurred between 1951 and 1970 (TSSWCB 1991) and some believe this may have happened because native prairie lands were plowed and put into crops. Kreitler and Jones (1975) identified natural soil nitrogen as the predominant source of nitrates in groundwater of Seymour aquifer. Others think that the sudden jump in nitrate level between the 1950s and 1970s could be attributed to the sharp increase in commercial fertilizer use. Kreitler (1979) stated that the high nitrate concentrations of the Seymour aquifer resulted from cultivation with ammonium-type fertilizers in the fields and animal wastes in the barnyard areas.

Intensified agricultural activities have increased concern because they usually include increased applications of nitrogen fertilizer. In addition, increased crop acreage has been primarily associated with irrigated agriculture. Sandy soils, along with the shallow depth to water (25-27 feet on average), create a potential for pollutants to leach into the aquifer relatively quickly. With nitrate concentrations already near or above established safe drinking water standards, attention to this potential increase is needed.

Related literature

The 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 on nonpoint-source pollution, including this study, are increasingly relying on

biophysical models. Jacobs and Timmons (1974), Jacobs and Casler (1979), Park and Shabman (1982), and Heimlich and Ogg (1982) presented early examples of bioeconomic integration. They have been followed by L. Christensen (1983), Anderson, Opaluch, and Sullivan (1985), Setia and Magleby (1987), Gardner and Young (1988), Lee et al. (1988), Dillon, Mjelde, and McCarl (1989), Braden, Hericks, and Larson (1989), Bouzaher, Braden, and Johnson (1990), and Bryant et al. (1992). They document the reliance that is being placed on biophysical aspects in conjunction with economics.

By integrating plant simulation, hydrologic, and economic models of farm-level processes, Johnson, Adams, and Perry (1991) 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. Mapp (1991) 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, on per acre nitrogen applications, and on the availability of selected pesticides identified as likely to leach through the plant root zone. They evaluated runoff and percolation of nutrients and pesticides, irrigation water pumped, production, and net income associated with the baseline and alternative water quality policies.

A recent study (Taylor, Adams, and Miller 1992) examined economic incentives and other mechanisms to offset nonpoint-source pollution from agriculture. The authors linked EPIC to linear programming models for representative 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. In 1992, Carriker attempted to estimate the economic and environmental tradeoffs from managing nitrogen fertilizer in Great Plains corn production. The author used the CERES-Maize corn growth simulation model, corn yields, and a mass-balance approximation of environmental loading of nitrates to evaluate the net return risk under several economic incentive scenarios to reduce nitrate pollution. Results suggest that risk-averse farmers are likely to better manage nitrogen in response to the flex acreage provisions and/or economic incentives and to reduce nonpoint-source contaminants. Another study (Sabbagh et al. 1992) 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 results indicate surface irrigation results in larger leaching of chemicals than sprinkler irrigation.

Conner and Smida (1992) used the CERES plant simulation model, along with a multi-objective programming model to identify how alternative agricultural pollution abatement policies require 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.

Diebel (1992) 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 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.

Previous studies addressing groundwater quality have been limited to the analysis of pesticide and nutrient leaching to the bottom of the top soil profile or two meters. This study goes beyond that depth and estimates nitrate leaching through the vadose zone by adding an extended soil profile in the EPIC model. The soil profile of the vadose zone was specified by using well log data for the area.

Methodology and Data

Assessing nonpoint-source pollution from agriculture is extremely difficult due to complex linkages between physical and chemical relationships of soils and crops as well as the economic environment. The type of crops produced (extent of crop uptake of nitrogen and nitrogen fixation) and the management practices affect nitrate leaching. The impact of management practices on groundwater quality can be dramatically impacted by:

(1) weather;
(2) porosity and layering within the soil profile;
(3) depth of the materials that lie between the top soil and the groundwater surface (known as the dewatered or vadose zone); and
(4) occurrence of denitrification which releases nitrates from soil into the air.

Capturing the total biophysical process is essential in an analysis of agriculture's impact on groundwater quality. This requires a multidisciplinary approach where inputs from several disciplines are integrated with economic analysis. Such an analytical tool provides an opportunity to evaluate water quality implications of alternative policies.

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 and influenced strongly by weather. As a result, policy analysts increasingly rely on biophysical models which estimate or predict environmental flows and simulate agronomic processes. 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. Because of the high information requirement and lack of data for validation, such models may not always provide accurate predictions. However, if validated with site-specific data, these models can greatly diminish the uncertainty about nonpoint loadings under alternative scenarios.

EPIC-WQ Simulation Model

EPIC-WQ (Erosion Productivity Impact Calculator—Water Quality) was used to simulate crop yields and nitrate leaching through the vadose zone. EPIC, a sophisticated process model that simulates the interaction of the soil-climate-plant-management processes in agricultural production, includes physically based submodels for simulating weather, hydrology, sheet and rill erosion, wind erosion, plant nutrients, plant growth, soil tillage and management, and plant environmental control. Each submodel is linked sequentially and interactively with other submodels. The model was developed in the early 1980s as part of the United States Soil and Water Resources Conservation Act to assess the relationship between soil erosion by wind or water and crop productivity throughout the United States. Since then the model has gone through several extensive revisions and modifications. EPIC simulations have been performed on 163 test sites in the United States as well as in a number of foreign countries. These tests have shown that EPIC calculates valid results under a variety of climatic conditions, soil characteristics, and management practices (Williams et al. 1983). A recent version of EPIC (version 2275) was used for this study because of its improved handling of nutrients.

EPIC-WQ is a crop growth simulation model and traditionally includes a two meter soil profile. This precludes simulation of the leaching of nitrate through the vadose zone. To modify the EPIC-WQ model by incorporating the

vadose zone, thirty-six well logs were selected from a Texas Department of Water Resources' study on the Seymour aquifer (Harden and Associates 1978). These wells, situated around the town of Munday (Knox County, TX), have an average depth of about 26 to 27 feet, the same as the average water depth across the Seymour aquifer area. The vadose zone was divided into five layers and each layer was added below the top soil in the EPIC model. The well logs provide only a rough description of the soil profile, which is widely variable in the vadose zone. Thus, some generalization about the soil profile was necessary.

In applying most biophysical simulation models, coefficients and processes must be validated to reflect local conditions to ensure that results are applicable to the study area. Proper validation of models, such as EPIC-WQ, is complicated by a lack of data on nitrate leaching or runoff and soil erosion for the particular area. Because of this problem, EPIC-WQ has been validated for crop yields by using site specific data from the Texas Agricultural Experiment Station in Munday (Knox County) and from the Soil Conservation Service (Seymour Aquifer Hydrologic Unit Project) in Haskell. These include type, quantity, and timing of irrigation, fertilizers and pesticides, and various tillage operations. The simulated yields obtained from the EPIC-WQ approximate the yields reflected in SCS (Soil Conservation Service) crop budgets. Data on nitrate in irrigation water and nitrate in soil have been used from local well testing and soil testing results conducted by the Soil Conservation Service.

Using five weather seeds (five different sets of random numbers used to generate simulated weather for the area), the model was run for 50 years by conventional and alternative production methods for the area. These methods included alternative timing of fertilizer application (one time v. split application) and alternative quantities of fertilizer and irrigation used (conventional v. reduced fertilizer and irrigation). For cotton, where a split fertilizer application is used, the second application is made immediately after the first bloom.

To evaluate the impact of the Conservation Reserve Program (CRP) on aquifer water quality, EPIC simulations were conducted as follows:

(1) dryland cotton was simulated for 20 years;
(2) the soil profile from the output of the 20th year simulation was used and sorghum hay was produced for one year as cover crop for CRP;
(3) the soil profile from the output of sorghum hay was used as the starting point to grow pasture for nine years; and

(4) finally, the soil profile from the output of pasture was used as a starting point to return to dryland cotton simulation for 20 more years.

This assumes the CRP lands will go back to dryland cotton at the end of the CRP contract (10 years). The average nitrogen percolation was then compared with the average percolation under continuous dryland cotton for 50 years. Dryland cotton was chosen for this scenario because a high percentage of CRP lands in this area were expected to return to dryland cotton if the CRP contract were not renewed (Lamberth 1993). The extent of nitrate contamination from natural sources has been addressed by simulating native pasture production for 50 years.

Budgeting

Using the simulated 50 year average crop yields, average net returns were calculated for production practices with different methods of nitrogen and irrigation use. Net returns for conventional production methods have been calculated by the Soil Conservation Service (Seymour Aquifer Hydrologic Unit Project) in Haskell by applying the crop enterprise budget generator CARE (Cost and Return Estimator). Using the above budgets, net returns of different production methods were calculated by adjusting the cost of fertilizer, irrigation, and harvesting. For example, for a split fertilizer use method, cost of a second application of fertilizer was taken into account. For irrigated and dryland cotton, price of lint, price of seed, and the deficiency payment of \$0.54/lb, \$75/ton, and \$0.15/lb, respectively, were used. Dryland wheat price and the associated deficiency payment were assumed to be \$3.46/bushel and \$0.65/bushel, respectively.

The nature of tradeoffs between nitrate percolation and average net returns was investigated by plotting the returns-percolation data points for various production practices. A break-even analysis was then applied to estimate the cost of nitrogen where a farm would have economic incentive to adjust fertilizer practices to a lower level.

Results

The results provide insight into the effect of management practices on groundwater quality and possible tradeoffs between farmer profit and nitrate leaching. For this analysis, 18 nitrogen management strategies were evaluated

for dryland wheat and cotton and irrigated cotton. In addition, a CRP and a native pasture scenario were also investigated. For illustrative purposes a nitrogen fertilizer level above the conventional use was included. Due to the high percent of nitrogen formulation on dryland cotton, the result is an application of nitrogen actually above that on irrigated cotton. This elevated nitrogen use rate has a significant yield impact not shown on irrigated cotton. The implication is that fertilizer is being leached to a large extent by irrigation; therefore leaching depends upon the amount and timing of nitrogen use.

Besides nitrogen fertilizer, the amount of nitrate leached into the aquifer may originate from several other sources such as: nitrate in rainfall and irrigation water; existing nitrate and organic N concentrations in the soil profile; and nitrogen fixation by crops, crop residues, manure, and other unknown sources. Because of the complex biophysical linkages, it is extremely difficult to account for the percentage of nitrate leached from each of these sources. However, since the quantity of nitrogen and irrigation (for irrigated cotton) were varied, while other parameters remained constant, the results give a reliable *relative* measure of nitrate percolation from various methods of nitrogen management. The average depth of the aquifer is used to track nutrient movement, thus areas with higher aquifer depth may experience slightly different levels of percolation.

The concentration of leached nitrate (Table 1 and 2) for the cultivated crops are all above the EPA standard of 10 ppm. Nitrate concentration in the aquifer depends on the nature of recharge, extent of water pumping from the aquifer, direction of water flow inside the aquifer, and other complex variables. Whether one pound of leached nitrate with higher concentration is environmentally safer than five pounds of nitrate with lower concentration is not known because of these factors.

Crop Production Strategies and Water Quality

Tables 1 and 2 show the implications of alternative production strategies for cotton and wheat, respectively, as well as nitrate leaching for native pasture over 50 years. For irrigated cotton moderately higher water quality can be achieved by reducing nitrogen fertilizer use. As expected, irrigation plays the most important role in controlling water quality with irrigated cotton. *Split fertilizer/reduced irrigation* method can have a considerable positive impact on water quality with negative implications for crop yields. For dryland cotton nitrate leaching is less of a problem because supplemental water is not being added. However, though *reduced fertilizer* can prevent nitrate leaching almost

TABLE 1

ENVIRONMENTAL AND ECONOMIC IMPLICATIONS: IRRIGATED AND DRYLAND COTTON

Cropping Methods	Average Yield	Net Returns	Fertilizer Used	Irrig. Used	Nitrogen Leached into the Aquifer Max\Min	Avg	Concentration
	(Pounds)	($)	(Pounds)	(Inches)	(Pounds per acre)		(Parts per million)
Irrigated Cotton *(Higher Fertilizer)*	820	216	300 of 9-18-6 100 of 12-0-0	15	89\0	15	28
Irrigated Cotton *(Conventional)*	811	222	200 of 9-18-6 50 of 12-0-0	15	76\0	11	20
Irrigated Cotton *(Split Fertilizer / Reduced irrig)*	724	176	2*(100 of 9-18-6) 2*(25 of 12-0-0)	10	20\0	2	24
Irrigated Cotton *(Reduced Fertilizer)*	809	225	150 of 9-18-6 50 of 12-0-0	15	73\0	10	20
Irrigated Cotton *(Further Reduced Fertilizer)*	761	202	50 of 9-18-6 25 of 12-0-0	15	68\0	10	18
Irrigated Cotton *(No Fertilizer)*	677	151	0	15	46\0	7	18
Irrigated Cotton *(No fertilizer / further reduced irrig)*	562	103	0	5	31\0	1	18
Dryland Cotton *(Higher Fertilizer)*	390	136	300 of 20-8-0	0	28\0	3	26
Dryland Cotton *(Conventional)*	312	102	150 of 20-8-0	0	27\0	2	24
Dryland Cotton *(Reduced Fertilizer)*	267	78	100 of 20-8-0	0	20\0	1	24
Dryland Cotton *(Further Reduced fertilizer)*	210	46	50 of 20-8-0	0	0\0	0	0
Dryland Cotton *(No Fertilizer)*	177	30	0	0	0\0	0	0

*All numbers are rounded to the nearest whole number

entirely there is a significant drop in dryland cotton yield. For dryland wheat, as fertilizer use is gradually decreased, nitrate leaching drops from 14 lb/ac to 1 lb/ac. Furthermore, between the *conventional* and *reduced fertilizer* method, percolation declines from 11 lb/ac to 3 lb/ac without any large crop yield impact.

Nitrate percolation of the native pasture scenario (Table 2) suggests an average percolation of 1 lb/ac over the 50 year simulation. The comparison between conventional irrigated cotton and conventional irrigated cotton after 50 years of native pasture provide insight because some think that much of the

TABLE 2

ENVIRONMENTAL AND ECONOMIC IMPLICATIONS:
DRYLAND WHEAT AND NATIVE PASTURE

Cropping Methods	Average Yield	Net Returns	Fertilizer Used	Nitrogen Leached into the Aquifer Max\Min	Avg	Concentration
	(Bushels)	($)	(Pounds)	(Pounds per acre)		(Parts per million)
Dryland Wheat *(Higher Fertilizer Use)*	31	-2.51	150 of 32-0-0 75 of 46-0-0 (Spreader)	131\0	14	36
Dryland Wheat *(Conventional)*	31	2.18	125 of 32-0-0 50 of 46-0-0 (Spreader)	127\0	11	36
Dryland Wheat *(Slightly Reduced Fertilizer)*	29	-0.99	100 of 32-0-0 25 of 46-0-0 (Spreader)	79\0	8	26
Dryland Wheat *(Reduced Fertilizer)*	27	-6.79	75 of 32-0-0 25 of 46-0-0 (Spreader)	31\0	3	11
Dryland Wheat *(Further Reduced Fertilizer)*	24	-16.52	50 of 32-0-0 25 of 46-0-0 (Spreader)	29\0	1	11
Dryland Wheat *(No Fertilizer)*	5	-84.44	0 of 32-0-0 0 of 46-0-0 (Spreader)	0\0	0	0
Native Pasture	N/A	N/A	0	15\0	1	21

*All numbers are rounded to the nearest whole number

nitrate in the Seymour aquifer originated from natural sources when the native lands were originally cultivated. Our results show that continuous irrigated cotton after 50 years of native pasture lowered percolation (9 lb/ac) compared to conventional irrigated cotton without the native pasture scenario (11 lb/ac). Likewise, dryland cotton with ten years of Conservation Reserve Program (CRP) in the middle of the simulation period reduced nitrate leaching (1 lb/ac) compared to continuous dryland cotton for 50 years (2 lb/ac). This suggests that CRP is an effective means of controlling soil erosion and reducing nitrate contamination of the Seymour aquifer.

Economic Implications

The calculation of net returns (Tables 1 and 2) provides further insight into economic implications facing farmers in the Seymour aquifer along with the water quality implications. Figure 2 illustrates some economic implications where the relationship between crop yield, net returns, percolation, and nitrogen applied is plotted. For irrigated cotton *reduced fertilizer* was associated with a higher profit than *conventional* and *higher fertilizer* methods because the yield decline was small compared to the costs of more fertilizer (Fig. 2, top panel). Crop yield is not sensitive to fertilizer beyond 20 lbs. of fertilizer use which is reflected in net return figures. Though net returns sharply increase between 0 and 20 lbs of fertilizer use, it gradually declines if more than 20 lbs of fertilizer is used. *Reduced fertilizer* followed by the *conventional* production method yielded the largest profit for irrigated cotton.

Dryland cotton showed a strong, positive relationship between nitrogen use and net returns. Crop yield, percolation, and profit increased with successively higher nitrogen use (Fig. 2, middle panel). A nitrogen use level double that typically used on dryland cotton was simulated. The yield response without supplemental irrigation water may be overstated. Further examination of this scenario is warranted.

Dryland wheat production (Fig. 2, bottom panel) is not as profitable as irrigated cotton or dryland cotton. Higher fertilizer use above the *conventional* method does not bring higher wheat yield. This is reflected in net returns where a lower negative profit per acre was estimated with a successive higher use of nitrogen fertilizer up to the conventional method. Beyond that higher fertilizer use brings less profit as higher fertilizer cost is not compensated by higher yields.

Policy Implications

Efforts directed to reduce nonpoint-source pollution can help identify wiser production practices with equal or greater profit, or convince farmers to adopt less profitable but more environment-neutral production practices. For example, a tax on nitrogen is expected to increase the cost of production more for higher fertilizer using crops than for lower fertilizer using crops. Crop yield is more sensitive to lower levels of nitrogen fertilizer use, especially for irrigated cotton and wheat (Fig. 2). In the absence of any available data on the elasticity of nitrogen demand, this may lead us to assume that nitrogen demand elasticity is higher at higher levels of fertilizer use. Therefore, by providing an

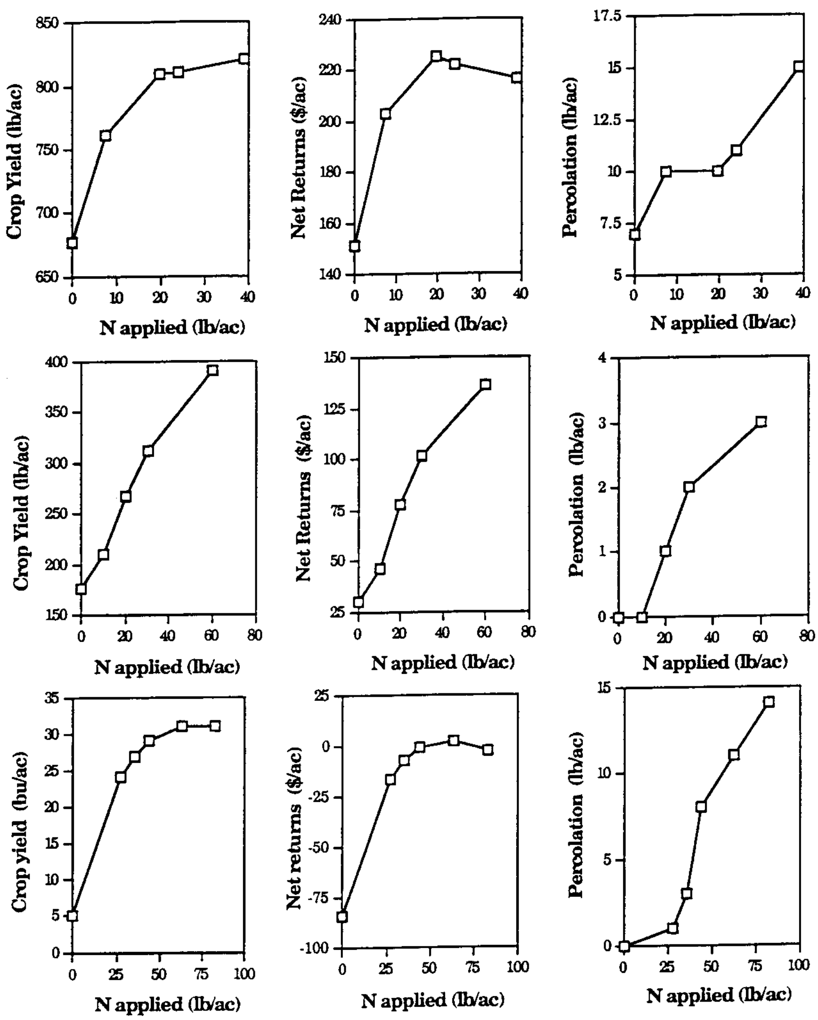

Figure 2. Relationship between crop yield and nitrogen applied, profit and nitrogen applied, and percolation and nitrogen applied: top panels (irrigated cotton), middle panels (dryland cotton) and bottom panels (dryland wheat.).

economic incentive, a nitrogen tax can induce farmers to move from higher fertilizer using production methods to reduced fertilizer methods of production. However, there are other possible effects including changing crops and input mix for a selected crop.

Nitrate percolation results from a combination of factors including weather, irrigation method, and timing of nitrogen use. The agricultural community's response to the tax is also unknown. With higher commodity prices due to supply shifts there may be a counter trend for some crops and use of higher fertilizer levels. It is also possible that farmers will farm more acres (substitute land for nitrogen fertilizer) and begin using highly erodible land. Due to the interactions and complexity of the agricultural production system, a macro analysis of a tax on nitrogen is needed to estimate impacts.

A break-even analysis was employed to calculate an approximate tax on nitrogen fertilizer where fertilizer use would adjust from higher to lower use in the Seymour aquifer region. By successively increasing the price of nitrogen fertilizer, a price was reached where the profit of a higher fertilizer use production method becomes equal to a lower fertilizer use practice. This break-even price minus the original price of nitrogen gives an estimate of the tax on nitrogen needed to provide an economic incentive to reduce use to a target level.

Figure 3 shows the nature of tradeoffs between nitrate percolation and farmer profit for irrigated cotton, dryland cotton, and dryland wheat, respectively. Profit for irrigated cotton (top panel) was estimated to increase from about $100/ac to $175/ac with an increase in percolation of only 1 lb/ac (from 1 lb to 2 lb). Further profit increases (up to $225) are associated with large increases in percolation (from 2 lb/ac to over 10 lb/ac). This suggests that the loss in profit is near $50 per acre to reduce nitrate percolation to the Seymour aquifer from over 10 lb/ac to about 2 lb/ac. A cost-share program of about $50 per acre would be needed to induce farmers to change production practices to achieve the lower percolation level in irrigated cotton. Alternatively, a regulation dictating a production strategy to achieve the same result would reduce farm profits about $50/ac. A tax on nitrogen could also achieve the reduction in use. In irrigated cotton, the highest fertilizer use scenario was not the most profitable method of production. However, fertilizer use was projected to decline with a tax of $.07 or more (from 39 lb to 20 lb). This reduced percolation from 15 lb/ac to 10 lb/ac. The reduction in per acre net return was 9% (from $216/ac to $199/ac).

For dryland cotton (Fig. 3, middle panel) net returns increased from $77 to $136/ac for higher uses of nitrogen and consequently increased percolation

from 1 to 3 lb/ac. However, beyond this point, net returns remain almost constant for higher fertilizer use. The higher nitrogen use levels on dryland cotton suggests a yield response beyond that supported by conventional fertilizer rates. Given this potential limitation, the loss in profit would be about $60/ac to reduce percolation from 3 lb to 1 lb/ac. This suggests that irrigated cotton holds more potential for programs to reduce nitrate percolation. In dryland cotton, profit is more sensitive to nitrogen use. As a result, a large amount of tax (considerably higher than $.07) would be necessary to equate the profit of higher fertilizer using production methods with lower fertilizer use methods. However, dryland cotton has lower percolation levels than irrigated cotton and wheat, and a tax of $.07 would provide some moderate incentive to switch to slightly lower fertilizer using methods.

For dryland wheat, with a decreasing use of fertilizer, farmer's profit decreases from $2.18/ac to $-16.52. A regulatory policy may not be appropriate for wheat where net returns are already low. A cost share program to reduce leaching from 11 lb/ac to 1 lb/ac would cost about $19/ac. This would require less funding compared to irrigated cotton. Therefore, if a cost-share program is considered to manage the water quality of the Seymour aquifer, it should be targeted to wheat first. The higher fertilizer method for wheat showed a negative profit. A $.07 tax on nitrogen to get a desired response in cotton greatly reduces the gap between the negative profit of *higher fertilizer* method and *further reduced fertilizer* method for wheat which is a useful crop in a rotation for this region.

Conclusions

This study examined the *relative* levels of nitrate percolation in the Seymour aquifer from alternative production practices. Although inconclusive, the results provide a useful scenario for explaining the nature of tradeoffs between nitrate leaching and farmer profit. The accuracy of this tradeoff could be greatly increased by including the effects of conservation tillage, crop rotations, different irrigation methods, other soil types, and risk behavior of farmers. A representative farm-level optimization model would capture the dimensions not addressed in a per acre analysis.

This analysis shows the difficulty of developing efficient and effective policy for controlling nonpoint-source pollution for a particular region. Though this paper addressed only groundwater, many other sources such as surface water, weather, and soil erosion from adjacent regions contribute to nonpoint pollution. The appropriate mix of incentives and regulations has major chal-

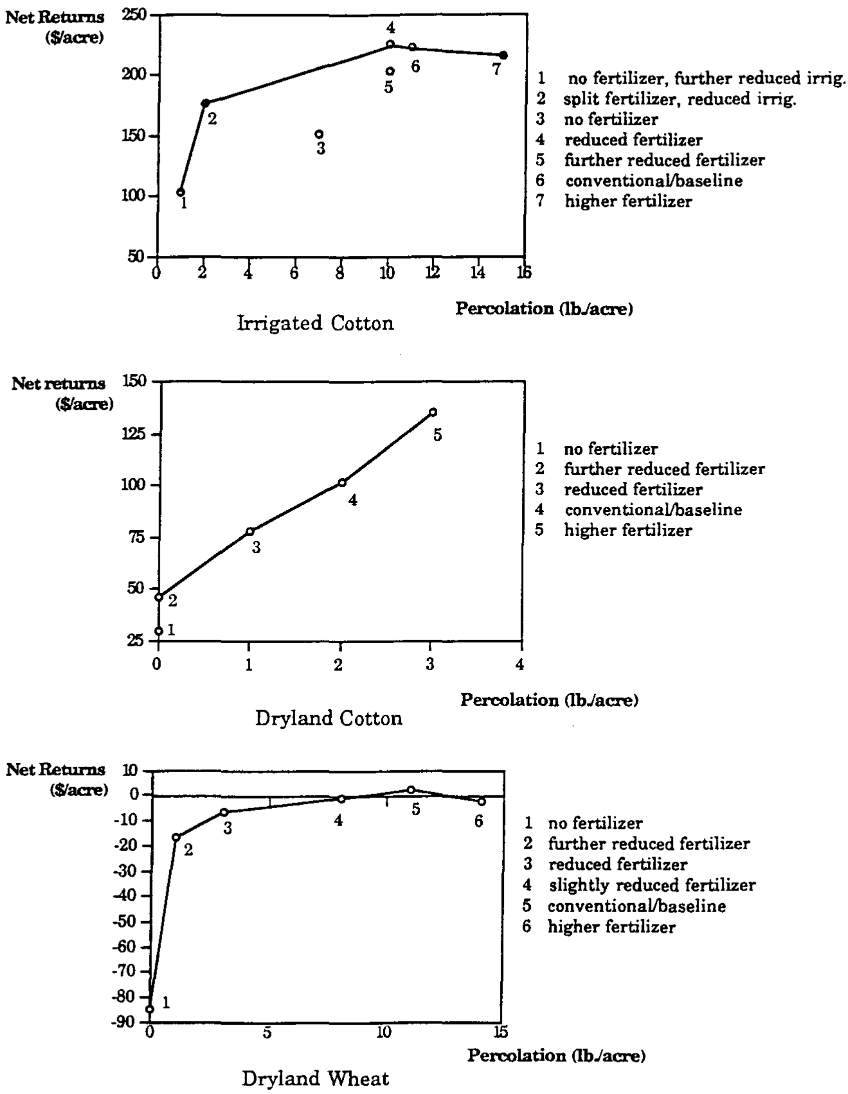

Figure 3. Tradeoffs between nitrate percolation and net returns.

lenges with regard to monitoring and enforcing. Furthermore, the issue of national versus a watershed approach arises. A national standard gives uniformity but does not take into account the uniqueness of a watershed, which requires infrastructure development and appropriate policies.

No matter how carefully policies are chosen, because of the stochastic nature of nonpoint-source pollution, the question of who, what, how, and when will always seem to be unresolved. Thus, we join other researchers in expressing a concern about how nonpoint-source pollution from agriculture can and will be addressed. Narrowing the information gap is undoubtedly the first major step towards solving the nonpoint-source pollution. This study served that purpose by contributing to the water quality data base for the Seymour aquifer.

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