AN ABSTRACT OF THE THESIS OF

Michael L. Taylor for the degree of Doctor of Philosophy in Agricultural and Resource Economics presented June 26, 1990.

Title: Farm Level Responses to Agricultural Effluent Control Strategies: The Case of the Willamette Valley

Abstract approved: Redacted for Privacy

Richard M. Adams

Changes in the structure of the U.S. agricultural industry since World War II have transformed it into a highly productive component of the domestic economy. But these changes have not occurred without indirect costs. For example, the reliance on agricultural chemicals has produced environmental effects causing growing concern. In addition, renewed awareness of and demand for environmental amenities by the general public are changing attitudes towards the agricultural industry and its implicit property rights. This public concern is prompting a growing use of regulatory controls for pollution problems, at a time of greater demands on water resources and declining farm sector population.

In this dissertation an examination was made of economic incentives and other mechanisms available to farmers to offset pollution, with particular application to

the Willamette Valley of Oregon. A two-part simulation was used, involving a biophysical model designed to simulate crop growth and nutrient flow, and separate economic optimization linear programming models of five representative farms. The output of each of the farm models is an optimal crop rotation mix and an associated set of nutrient outflows. Environmental restrictions and regulations were imposed when conducting policy tests, and changes in profit, crop mix, and physical outputs were recorded to provide a measure of policy effectiveness and cost. Policies tested included effluent charges, an input tax, per-acre standards, a required use of no-tillage, and a fall fertilizer ban.

The results indicate that the availability of production options on each farm influences policy effectiveness and the cost of achieving pollution abatement. Nevertheless, some abatement is possible on all farms for relatively little cost. Of the policy measures, effluent charges provide abatement at least cost, although specific levels of abatement may not be attainable. When a farm is subject to multiple pollution problems, control of one type of pollutant may exacerbate other problems. Finally, farmers in the Willamette Valley can reduce both nitrogen use and effluent with a greater use of crop rotations.

# Farm Level Response to Agricultural Effluent Control Strategies: The Case of the Willamette Valley

by

Michael L. Taylor

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Completed June 26, 1990

Commencement June 1991

APPROVED:

Redacted for Privacy

Professor of Agricultural and Resource Economics in charge of major

Redacted for Privacy

Head of Department of Agricultural and Resource Economics

Redacted for Privacy

Dean of Graduate School

Date dissertation is presented June 26, 1990

# ACKNOWLEDGEMENTS

It is not surprising to anyone who has completed a dissertation that the task can not be done alone. I would therefore like to acknowledge the respective roles of those who helped to make this project a reality.

I would especially like to thank my major professor, Richard Adams, for his wisdom, insight, patience, and support during the process. Rich knows economics; I always left our meetings knowing more than when I arrived. I would also like to thank Stanley Miller for his assistance in getting the idea underway, and for encouraging me to undergo the doctoral program in the first place.

My committee members also provided significant guidance: Olvar Bergland, for his attention to detail which greatly improved the final product; Alan Love, for providing me quantitative tools and direction; Frank Conklin, for his insight into the agriculture industry; and Doug Brodie, for his thoughtful comments on the final product.

It should also be noted that the funding for much of my graduate program was provided by Solutions to Economic and Environmental Problems (STEEP), a research consortium of Federal, State, and Local entities. For their generous support, I am grateful.

A disseratation's development requires a certain amount of quality "down" time, necessary for reflection and ripening of ideas. I would like to thank Donald McLeod for his role in a good part of that time, for pots of coffee and more than a few beers. I wish him well in his endeavors.

Finally, a considerable amount of gratitude must go to my wife, Elizabeth. She provided assistance in collecting information on the laws of Oregon, as well as considerable support (both moral and financial). I appreciated her patience, encouragement, and understanding. It is to her that I dedicate this dissertation.

> "Conservation is getting nowhere because it is incompatible with our Abrahamic concept of land. We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect. There is no other way for land to survive the impact of mechanized man, nor for us to reap from it the esthetic harvest it is capable, under science, of contributing to culture."
>
> \- Aldo Leopold

> "We know too much about ecology today to have any excuse for the many abuses that are currently going on in the management of the land, in the management of animals, in food storage, food processing, and in heedless urbanisation. If we permit them, this is not due to poverty, as if we could not afford to stop them; it is due to the fact that, as a society, we have no firm basis of belief in any meta-economic values, and when there is no such belief the economic calculus takes over."
>
> \- E.F. Schumacher

> "Nature bats last."
>
> \- A bumper sticker

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

## LIST OF FIGURES

## LIST OF TABLES

LIST OF TABLES (Continued)

# FARM LEVEL RESPONSES TO AGRICULTURAL EFFLUENT CONTROL STRATEGIES: THE CASE OF THE WILLAMETTE VALLEY

## I. INTRODUCTION

Agriculture is considered one of America's greatest productivity success stories. Since the Second World War a combination of factors has transformed U.S. agriculture, allowing more food to be produced on less land by fewer farmers. Publically funded research and a range of other federal programs have led to technological developments in genetic materials, fertilizers, pest control mechanisms, mechanical devices, and food storage, processing and marketing systems. Together, these developments have resulted in high productivity, high quality products, and low consumer prices, and have provided the foundation for the role of the U.S. agricultural sector in world markets.

These changes in the structure of the agriculture industry are not without costs. For example, the reliance on agricultural chemicals has produced environmental and other side effects that concern both agriculturalists and non-agriculturalists. In addition, renewed awareness of and demand for environmental amenities by the general public are changing attitudes towards the agricultural industry and its implicit property rights. Some of these concerns about traditional agricultural methods were summarized by the U.S. Department of Agriculture [1980, p. xii], and include:

(1) Sharply increasing costs and uncertain availability of energy and chemical fertilizer, and the heavy reliance on these inputs.

(2) Steady decline in soil productivity and tilth from excessive soil erosion and loss of soil organic matter.

(3) Degradation of the environment from erosion and sedimentation and water pollution by agricultural chemicals.

(4) Hazards to human and animal health and to food safety from heavy use of pesticides.

(5) Changes in the nature of the family farm and localized marketing systems.

The relative ranking of these general classes of problems is subject to debate, but degradation of the environment is certainly one of the more visible to the general public. This public concern is prompting the growing use of regulatory controls for pollution problems. The use of regulatory controls is occurring at a time of greater demands on water resources and declining farm sector population. One of the major components for assessing the future relationship of agricultural activities and the environment is an examination of alternative production systems available to farmers to offset pollution from agricultural sources. The effects of control mechanisms and production systems on farm level profitability can suggest their likelihood of adoption. The assessment reported in this dissertation provides insight into the effectiveness of efforts towards achieving desired social goals of a sustainable food supply and a clean environment.

**A. Dissertation objectives.**

The overall objective of this research is to assess farm-level responses to alternative regulatory policies that may reduce soil erosion and nutrient flow. Economic efficiency, effectiveness in reducing pollutants, and distribution effects will serve as criteria for such an assessment. Specific research objectives are:

1) To model crops, rotations, and tillage practices on common soils consistent with options available to farmers of the Willamette Valley of Oregon, using the EPIC (Erosion-Productivity Impact Calculator) biophysical simulator;

2) To simulate management options over a twenty-five year period using the EPIC model to obtain relative yields and environmental outputs;

3) To build economic models of representative farms of the valley; and

4) To optimize farm-level options under imposed environmental restrictions on nutrient flow (nitrogen and phosphorus) and soil erosion.

The research will contain estimates of the economic effects on a broad, regional scale to provide perspective for social welfare analysis.

This study will seek to enhance the understanding of the relationships of farm management, tillage practices, runoff control, and water quality. It will also add an economic dimension to the analysis of so-called "best management practices," with consideration of their general effects on water quality. While preliminary, the economic evaluation of management options performed here can guide future research in assessing off-site benefits and tradeoffs from soil conservation measures and water quality enhancement.

**B. Problem statement.**

Though the problems of soil erosion and water quality have been studied for many years, the economic relationships of commercial agriculture, pollution and farm management alternatives are not well understood. Changes in management (through crop rotations, crop mix, sources and application levels of nutrients, and pest control) and tillage practices (such as deep plow, minimum tillage or no-till) affect surface and ground water quality. Their interrelationship with water quality, and how water quality regulation affects the choice of management or tillage, are increasingly important considerations for farmers, conservation agencies, and policy planners. Therefore, the choice of appropriate mechanisms for effecting changes in externalities depend upon the objectives of the planners, net economic impacts on producers, and spatial distribution of these economic impacts. In addition, consideration must also be given to other objectives (such as income enhancement or stabilization, health, and environmental quality) when considering changes in policy. Empirical evidence is an important input in the resolution of these policy issues.

The empirical focus of this study is on the Willamette Valley of Oregon. The Willamette Valley represents an important diversified agricultural region in the Pacific Northwest. Its climate consists of mild summers and cool winters with heavy precipitation. Important commodities include grass grown for seed, hay for cattle and dairy farms, and small grains; other crops include vegetables for processing, berries and horticultural products [Miles]. The Willamette Valley also contains nearly 80% of the state's population [U.S. Department of Commerce 1983].

Though soil erosion problems in the area have not always been considered significant in general [N. Christensen], a U.S.E.P.A. water quality survey ranked the Willamette River Basin in the highest category of phosphorus, inorganic nitrogen and total nitrogen levels, relative to other parts of the United States [Omernik]. In addition, Oregon is one of 17 states where agriculture has been identified as a primary or major nonpoint source of water pollution [U.S. Environmental Protection Agency].

Under increasing social pressures for competing uses of water resources, it is important to understand and determine the role of agriculture in pollution problems and farm level management responses to reduce agriculture's contribution to pollution.

### C. The challenge to researchers.

Water quality research has been underway since the early seventies. L. Christensen, in his review of fifteen years of research, describes the early years as the "learning period," with much work still needed in estimating offsite costs and benefits of improved water quality due to the control of agricultural non-point source pollution [p. 54]. Another important need is defining and deriving the empirical relationships between so-called "Best Management Practices" and the quality of receiving streams as indicators of pollution.

The lack of substantial empirical data on water processes and nonpoint pollution suggests the importance of water quality modeling in conducting analyses. Bailey and Swank infer:

> "Whereas the 1970s was the era of model conceptualization, development and linkage, the 1980s should be the era of model testing, application for regulatory decision making, refinement, and cost-effectiveness assessment." [p. 41]

Batie, in conclusion, suggests the direction to be taken in water quality research:

> "When agriculture is perceived as the problem, agricultural institutions need to respond constructively. Researchers must reorient intellectual efforts from a primary focus on the economic consequences of chemical research for farmers, to also include consideration of the consequences these chemicals have on the environment." [p. 7]

**D. Agricultural externalities.**

One of the primary national environmental concerns about agricultural production methods is their effects on the quality of water and subsequent impacts on wildlife, human and animal health, water treatment costs, and recreational activities. These environmental damages arise from three processes: (1) soil erosion resulting in sediment deposited off the farm field, (2) fertilizer and pesticide runoff deposited directly in surface water courses, and (3) fertilizer, nutrients and pesticides percolating into groundwater. Among the categories of water pollution, these are referred to as *non-point source (NPS)* pollutants, and are the most common form of agricultural effluent.

*D.1 Nature of NPS pollution.*

Non-point source pollution is that which occurs over a broad area and for which an individual discharge point cannot be identified. The significance of NPS pollution lies in the fact that regulation, control, and containment is considerably more difficult to implement than with point-source pollution, for which the discharger and volumes are more easily identified and measured.

As industries and municipalities succeed in cleaning up their wastewater discharges, non-point sources have become the major source of water pollution in the United States. They are responsible for 99% of the suspended solids (sediment), 83% of the dissolved solids (salinity), 82% of the nitrogen, 84% of the phosphorus and 98% of the bacteria loads in U.S. waterways [Clark, et al.].

Agriculture is the largest source of NPS pollution; in fact, the U.S.E.P.A.'s most recent National Water Quality

Inventory (1978) describes agriculture as the most widespread non-point source of pollution, affecting two-thirds of the nation's water basins [Duttweiler and Nicholson, p. 3]. Giannessi and Peskin modeled national NPS loadings in U.S. waterways (table I-1); their estimates found that agricultural sources are responsible for nearly half the biological oxygen demand (BOD), three quarters of the total dissolved solids, and over 97% of total suspended solids.

Table I-1. U.S. annual discharge of pollutants to waterways, in millions of tons, by source and type.

| Type*: | BOD | TSS | TDS | Total P | Total N |
|---|---|---|---|---|---|
| Point source: | | | | | |
| Industrial | 3.8 | 22.9 | 131.9 | 0.16 | 0.25 |
| Municipal | 2.6 | 2.7 | 14.5 | 0.05 | 0.50 |
| Total | 6.4 | 25.6 | 146.4 | 0.21 | 0.75 |
| Agricultural nonpoint source: | | | | | |
| Cropland | 3.2 | 479.2 | 216.3 | 0.43 | 2.37 |
| Woodland | 0.8 | 97.3 | 55.4 | 0.12 | 0.49 |
| Pasture | 0.5 | 78.8 | 32.8 | 0.07 | 0.34 |
| Range | 1.8 | 423.9 | 172.8 | 0.54 | 1.45 |
| Total | 6.3 | 1,079.2 | 477.3 | 1.16 | 4.65 |

* Pollutant types: Oxygen demanding wastes (BOD), Total suspended solids (TSS), Total dissolved solids (TDS), Phosphorus (P), Nitrogen (N)

Source: Giannessi and Peskin 1981.

The most serious and most common types of pollutants found in agricultural non-point sources are bacteria, nutrients, dissolved solids (salinity), suspended solids (sediments), pathogenic organisms, and toxic materials. Runoff is the primary source of bacteria, sediment, nutrients and pesticides. Among these, pesticides are generally considered the largest source of toxics. Though concentrations and persistence of most pesticides in current use are low, some are so toxic that even low levels cause concern [L. Christensen, p. 38].

Even if sources of pollution can be identified in a general manner, volumes of output do not determine physical damage levels; in fact, water quality should be defined in terms of the impaired uses of that water. Damages to a water source from pollution in high demand by alternative users will be significantly greater than to one with little demand and many alternative sources.

In addition to identification problems, particular characteristics of non-point source pollution also complicate proper assessment of the problem. The characteristics include: (1) nonpoint source discharges are diffuse in nature and primarily occur during rainfall events; (2) nonpoint source pollution is a stochastic, dynamic process with multimedia dimensions; (3) nonpoint source discharge of some chemicals may have no apparent direct adverse impacts in the receiving medium [Bailey and Swank, Jr., p. 29].

*D.2 Externalities and economic damage.*

An externality is an output or effect of the production process for a commodity whose cost is not borne by the producer and which is not sold in the marketplace. (A formal definition of an externality appears in Chapter II, section D.1.) Externalities result in inefficiency because resources are not allocated according to their true relative prices, and some commodities (for example, from a polluter) are overproduced and others (community health) are underproduced.

In agriculture, production externalities take the form of soil erosion and agricultural runoff, among others. In the process of growing crops, loosened topsoil that has moved to a streambed imparts additional costs on other users of that water. Sedimentation and nutrients can harm fish and cause turbidity and excessive plant growth, reducing recreational opportunities on waterways. While soil erosion has a direct effect on crop productivity by removing soil nutrients and reducing soil water-holding capacity, institutional barriers, the substitution of technologies for lost soil, agricultural policies favoring intensive production, and the relatively small annual financial impact of productivity loss due to erosion reduce the incentives for adoption of erosion control measures. Thus, the damage caused to stream users is not borne fully by the farmer.

Soil erosion control has been studied by researchers for more than fifty years with the primary focus at the farm level; however, contemporary soil erosion rates are almost as severe as fifty years ago, despite a federal investment of $15 billion and "many billions of dollars" more by farmers [Colacicco, et al., p. 35]. Though the linkage of erosion to pollution of water has long been known, little progress has been made in its widespread control.

Part of the reason for lack of success is suggested by Batie [p. 5]: agricultural professionals are not accustomed to being perceived as a polluting industry; they see water quality as mostly an information problem. They argue for more education, more technical and cost-sharing assistance, and more research, and believe farmers will voluntarily improve efforts to protect water quality. Finally, they feel that no reallocation of property rights is necessary.

Many non-agriculturalists, however, see public policy and direct controls, or a redefinition of property rights, as the solution. Regulation (rather than cost-sharing) provides a "top-down" mandatory approach rather than a "bottom-up" voluntary approach [Batie, p. 5]. Recent years have seen the implementation of such regulations: Arizona requires permits for all fertilizer applications; fertilizer use regulations have been imposed in Mississippi and Nebraska; and fertilizer taxes are now in effect in Iowa, Wisconsin, and Illinois [Ferguson, et al., p. 12].

But regulation is not without cost. In general, regulation raises the cost of agricultural production, with direct implications for consumers' welfare. While aggregate returns to producers may increase, distributional consequences may be severe and counter to the goals of such regulation [Daberkow and Reichelderfer, p. 12]. In addition, different forms of regulation can lead to different levels of input use, output, profits, and environmental damage [Helfand, p. 2].

**E. Dissertation organization.**

This dissertation contains five chapters. The next chapter contains a discussion of the bioeconomic problems and complexities surrounding agriculture and the environment, including the physical, technical, institutional and economic parameters. The third chapter is a description of the methodology for analysis, and includes the models and aggregation techniques. Two subsections contain details on soils and crops and their influences on production methods and incentives.

Chapter four contains the results and analysis of the simulations and optimizations. The final chapter contains a summary, limitations, conclusions, and suggestions for future research.

## II. PHYSICAL, INSTITUTIONAL, AND ECONOMIC DIMENSIONS OF AGRICULTURAL EXTERNALITIES

The economic costs of off-farm environmental damage from commercial agricultural production is difficult to quantify but is nevertheless significant, given that agriculture accounts for about half of all water pollution [Chesters and Schierow]. Estimates of surface water damage from agricultural sources range from $2 to $16 billion per year [National Research Council, p. 98].

Though environmental damage from agricultural activity has been noted for many decades, government involvement has been relatively recent and limited. Non-point pollution control has been usually in the form of education and voluntary participation. Changing public perceptions of implied property rights over soil and water resources suggests that further involvement, through regulations and mandatory controls, is likely to increase.

The major dimensions of the agricultural pollution problem are detailed in the next four sections of this chapter. First, the physical components of agricultural externalities are identified, and their current and estimated future levels are presented with particular emphasis on the Pacific Northwest. This is followed by an overview of the technical and managerial production options available to farmers, and includes historic and projected trends of use.

The institutional approaches to water quality protection are summarized in the third section, including the history of government involvement at the federal level and by the state of Oregon. Finally, the last section contains a discussion of the bioeconomic problem, with the theoretical and policy options available for its correction.

**A. Physical dimensions.**

The interdependent nature of agricultural activity and environmental factors makes it difficult to pinpoint the physical components of agricultural NPS pollution responsible for external damage. Nevertheless, it is generally regarded that soil erosion (sediment), fertilizer leachate and runoff, and pesticides are the sources responsible for the vast majority of environmental damage off the farm field.

*A.1 Soil erosion.*

On-farm productivity can be adversely affected when soil erosion removes nutrients or reduces soil water-holding capacity. However, there is substantial evidence that soil erosion damage occurring off the farm is a greater problem than on-farm productivity loss (see, for instance, Clark, et al.; Crosson; Ribaudo; and Taylor and Miller).

Soil eroding from farmland can deposit sediment, fertilizer chemicals and pesticides in rivers and streams, on roadways or in ditches. Damages from sediment include:

habitat alteration and other adverse effects upon aquatic life, the filling of reservoirs and water courses, the increased cost and complexity of treating water supplies for municipal and industrial use, and the reduction of recreational value of water bodies [Duttweiler and Nicholson]. Sediment can also increase flood damage, fill water conveyance systems, and affect irrigation equipment performance.

In the U.S., soil erosion is occurring at an average annual rate of more than 9 tons/acre -- nearly twice the rate considered acceptable by some soil conservationists [Dempster and Stierna]. About one-fifth of U.S. cropland is subject to serious damage from erosion [Clark, et al.]. The Pacific Region contains some of the highest per-acre cost damage estimates in the United States, particularly in the categories of water storage, freshwater recreation, and marine fisheries [Ribaudo].

Crosson and Brubaker made projections of anticipated erosion rates and levels for the year 2010. Using an agricultural sector model developed by the Center for Agriculture and Rural Development at Iowa State University, the authors estimate that the Columbia-North Pacific region will have 88.2 million tons of erosion, and 5.2 tons of erosion per acre annually [p. 146]. Sediment delivered to water bodies in the Pacific region would be 30.8 million tons in 2010, as compared to 11.2 million tons in 1977. This would be true even with a "significant expansion" of amount of land in conservation tillage [p. 148]. The authors conclude:

> "How serious the deterioration [of the nation's surface waters] would be perceived to be we are unable to say, but we suspect it would be considered of significant national concern, justifying firmer measures to deal with erosion than any previously adopted." [Crosson and Brubaker, p. 149-150]

*A.2 Fertilizer runoff and leachate.*

Not all applied fertilizer is used by plants. Research in many states has shown that crops use only 50 to 70 percent of applied nitrogen fertilizer [Johnson, p. 130]. The remainder is either transported by erosion or runoff, leached, or chemically transformed and lost to the atmosphere.

The concern about fertilizer nutrient loss relates to the effects of nitrogen on human and animal health, and the role of nitrogen (N) and phosphorus (P) in accelerating eutrophication[1] through the stimulation of growth by aquatic plants. Plant growth can restrict navigation; reduce recreational values; produce undesirable tastes and odors in water supplies; and deplete dissolved oxygen when decomposing, causing fish kills.

Excessive nitrates ($NO_3$-) in drinking water have been linked to methemoglobinemia disease (blue baby) in animals and infants. At high levels, N in water can be toxic to

[1] Eutrophication is a process involving nutrient enrichment of lakes and reservoirs, the resultant growth of plant life, and subsequent decline in dissolved oxygen.

humans and animals, and N in ammonia can kill or injure fish [Miranowski; Crosson and Brubaker, p. 105].

Plant nutrient use in the U.S. nearly tripled from 1960 to 1981, with a substantial increase in nitrogen fertilizer. Not only did total quantity expand but quantity per acre increased. The amount of nutrients delivered to surface and ground water likely increased as well [Miranowski].

Nitrogen and nitrates. Nitrogen is generally applied in the form of ammonium ($NH_4$+), which over time is transformed into nitrate ($NO_3$-). Nitrates are easily absorbed by plants, but are highly soluble, making them prone to leaching under irrigation or precipitation. Bare soils lose more $NO_3$- to leaching for lack of absorbing plants, and coarse soils leach more than fine-textured soils.

The extent of damage from fertilizer nitrates is unclear. Numerous studies have shown the presence of nitrates in ground water, and some have linked nitrates directly to nitrogen-fertilization rates [Hallberg, p. 4], but it is not clear if fertilizer is the primary source. The extent of nitrate pollution in surface waters in the U.S. is also unclear, and less investigated than sediment. There is some indication of increasing levels of nitrates in rivers, but it is probably still below the "maximum acceptable amount" [Crosson and Brubaker, p. 107].

Nitrogen and phosphorus in water bodies are mostly due to municipal and industrial discharges, and the natural leaching of nutrients already in the soil. A report by the Council on Environmental Quality, however, suggests ground water contamination problems were limited to "hotspots", with fertilizer contamination the primary source in the Souris-Red-Rainey basin of Minnesota, and in the Pacific Northwest. U.S.E.P.A. studies in 1972 and 1977 found two-thirds of 800 lakes measured across the United States were eutrophic [Crosson and Brubaker, p. 109].

<u>Phosphorus.</u> Public and scientific concern about lake eutrophication focused attention in the 1950's and 1960's on phosphorus. About 6 million tons of $P_2O_5$ are used annually in the U.S. [White and Plate]. When applied to soil, most of it is either taken up by the plant, immobilized by adsorption on clay, or precipitated as iron or aluminum phosphate [Bailey]. Vertical movement of phosphorus to ground water is normally not a problem, but movement to surface water, via runoff, is a problem, since little phosphorus is needed to stimulate eutrophication under some conditions [Duttweiler and Nicholson].

<u>Projections of fertilizer use.</u> Crosson and Brubaker made projections of fertilizer use and subsequent nitrate problems based on anticipated acreage levels for the most commonly grown crops. These predictions are summarized in table II-1. Given that corn receives the greatest amount of

nutrient applications, leaching is expected to be higher in parts of the Corn Belt. However, applications of nitrogen and phosphorus to wheat acreage is expected to more than double.

Table II-1. Fertilizer applied to agricultural land (millions of metric tons), estimated and projected.

| | 1977/79 Estimated | | | 2010 Projected | | |
|---|---|---|---|---|---|---|
| | N | P | K | N | P | K |
| Corn | 3.97 | 1.93 | 2.15 | 5.96 | 2.64 | 3.24 |
| Wheat | .87 | .41 | .18 | 2.01 | .90 | .41 |
| Soybeans | .10 | .30 | .61 | .25 | 1.09 | 1.73 |
| Cotton | .31 | .16 | .08 | .25 | .15 | .09 |
| Subtotal | 5.25 | 2.80 | 3.02 | 8.47 | 4.78 | 5.47 |
| All Other | 4.18 | 2.11 | 2.28 | 9.18 | 3.46 | 4.48 |
| Total | 9.43 | 4.91 | 5.30 | 17.65 | 8.24 | 9.95 |

Source: Crosson and Brubaker [p. 77], and adapted from U.S. Department of Agriculture, <u>1981 Fertilizer Situation</u>, FS-10.

They conclude that the increase in movement of nutrients to water bodies is expected to be proportionally less than the total increase in fertilizer applications, due to a decrease in total acres of cropland, more efficient fertilizer technologies, and an increase in the use of conservation tillage:

> "Even allowing for the spread of more efficient nitrogen materials and practices, the projections of nitrogen applied in the South, Southwest, Mountain Region and Pacific Coast imply substantial percentage increases in nitrate losses in these regions." [Crosson and Brubaker, p. 116]

*A.3 Pesticides.*

The loss of pesticides from farm fields causes concern because these chemicals pose threats to human health and reproductive capacity. They also cause damage to non-target species of plants, insects, soil and water microorganisms, and wildlife. Runoff from agricultural land has been shown to be a major source of low level (1 ppb or less) pesticide contamination in surface waters [Duttweiler and Nicholson].

Table II-2 contains a breakdown of acreage for major crops on which pesticides were used. The vast majority of pesticides are used on cotton and corn.

Table II-2. Percent of acres on which pesticides were used, 1976.

| | Herbic. | Insect. | Fung. | other | Any pesticide |
|---|---|---|---|---|---|
| Corn | 90 | 38 | 1 | 1 | 92 |
| Cotton | 84 | 60 | 9 | 34 | 95 |
| Wheat | 38 | 14 | 1 | <1 | 48 |
| Sorghum | 51 | 27 | - | <1 | 58 |
| Other grain | 35 | 5 | 2 | - | 41 |
| Soybeans | 88 | 7 | 3 | 1 | 90 |

Source: Crosson and Brubaker [p. 80], adapted from T.R. Eichers, P. Andrilenas, and T.W. Anderson, <u>Farmers' Use of Pesticides in 1976</u>, USDA-ERS, Ag. Economic Report no. 418, 1978.

By region, the Pacific states (California, Oregon and Washington) are the largest users of herbicides for wheat by volume, at 8.15 million pounds in 1976 [Crosson and Brubaker, p. 82]. The most significant factor affecting herbicide use is the growth of conservation tillage, which uses greater amounts of herbicides per acre. However, the Pacific region (as of 1981) had just 12.8% of its cropland in conservation tillage, the smallest percentage of any region. Therefore, growth of herbicide use in the Pacific is unclear.

Nevertheless, Crosson projects conservation tillage to spread to 50 to 60 percent (from the present 25 percent) of the nation's cropland by 2010, and that herbicide use on wheat will grow 27.9% from 1976 figures. Crosson and Brubaker conclude:

> "The possibilities of presently undetected or potential future environmental damages of herbicides are sufficiently likely, in our judgment, to justify intensive, continuing investigation of herbicide-environment relationships, and a wary attitude toward the expanding use of herbicides. Adopting such an attitude, we nevertheless conclude that present knowledge does not suggest that the projected expansion of herbicide use will pose a major threat to the environment." [p. 127-28]

## B. Technical dimensions: tillage and management practices.

### *B.1 Tillage practices.*

Along with crops and rotations, farmers face decisions about methods of preparing soil for the planting of seeds. These decisions are generally made in the medium- to long-run as they often involve some capital investment. In some cases tillage and management practices are synergistic (as in some low-input systems); in others, tillage method and management practices are independent (such as for many conventional practices). The technical options available to farmers are outlined in this section.

Conventional tillage. Loosely defined as the "predominant" method of soil surface refinement for a crop, conventional tillage has usually involved a deep or heavy mold-board plow. This device breaks up and pulverizes the soil surface, leaving little or no residue ("clean till") from the previous crop. While it effectively discourages disease, a clean-tilled field is also left unprotected from the erosive elements of precipitation and wind. There is generally less organic content in a field that has been continuously plowed, which reduces water-holding capacity and tilth [National Research Council, p. 119].

Conventional tillage contributes to pest control by destroying some perennial weeds, disrupting the life cycle of some insect pests, and burying disease inoculum. At the same time it creates more bacteria activity and has a "boom-and-bust" effect on nutrient cycling processes (as opposed to the slow and even release characteristic of other tillages) [National Research Council, p. 160].

Conventional tillage has been in decline for a number of decades, though it is still used on more than two-thirds of the planted acreage in the U.S. Its reduction has been attributed to the economic advantages of conservation tillage and, more recently, government programs which encourage conversion. Use of conventional tillage is expected to decline further in the future [Crosson and Brubaker, p. 96].

Conservation tillage. The broad class of conservation tillage (CT) includes those practices which minimally disturb the soil surface and leave high levels of field residue. It includes shallow-tillage devices, chisels, and no-till drills. Of the nearly 100 million acres farmed using conservation tillage, most is in the form of mulch or reduced tillage; a smaller amount is in no-till [National Research Council, p. 156].

Conservation tillage is very effective in protecting soil from erosion. It works best in well-drained soil and in areas with a longer growing season (because it delays planting), and where there is a lack of serious weed problems (which can't be controlled by herbicides) [Crosson and Brubaker, p. 100].

The residue left on the soil surface may provide a favorable habitat for diseases and insects, and the effects on subsequent crops can be more severe, particularly if the same crop is planted the next year. These effects may be inconsequential or minimized in a rotation [National Research Council, p. 158]. Nevertheless, more pesticides are generally applied in a CT system than in a monoculture.

Conservation tillage improves the water-holding capacity of soil, and improves water infiltration. This, however, increases the susceptibility of nitrogen to leaching below the root zone. The overall effect of conservation tillage on water quality is mixed. According to Crosson and Brubaker, CT reduces erosion (but increases concentration of runoff), and a number of studies have demonstrated that most N and P movement is by eroded soil. Organic N deposited is mineralized to nitrate form only very slowly, so (the authors assert), CT will not significantly reduce the impact of N on water quality; however, just 5 to 40% of P carried by soil is available to support aquatic plant growth [p. 113]. The authors conclude:

> "...[C]onservation tillage may pose a greater threat to ground water quality than conventional tillage because of increased leaching of nitrate-N, but that the comparative effects on delivery of nitrate-N to surface waters is too dependent on specific local conditions to warrant a general conclusion....While we cannot say how the shift to conservation tillage would affect delivery of phosphorus and nitrate-N to surface waters, it seems reasonably well established that the shift would increase movement of nitrates to ground water." [p. 114-15]

With respect to phosphorus, the effect is not clear. In general, the advantage of CT with respect to total available P delivered to water bodies will be greater (1) the greater the reduction in erosion, (2) the smaller the difference in concentration of total P in sediment between conventional and CT, (3) the greater the ratio of available P to total P in sediment, (4) the higher the sediment delivery ratio, (5) the smaller the difference in concentration of P in runoff water between the tillages [Crosson and Brubaker, p. 114].

Conservation tillage requires greater use of pesticides. One important environmental issue is the tradeoff between the use of minimum tillage to reduce sediment and increased pollution from pesticide residues [L. Christensen, p. 50]. According to L. Christensen, one water study (by Heimlich and Ogg) concluded that erosion control strategies are compatible with pesticide exposure control at high levels of erosion control, and that the environmental characteristics of particular pesticides are more important than their volume.

Conservation tillage is expected to become much more widespread in the future; Crosson and Brubaker expect an increase from roughly a quarter of the nation's cropland (in 1981) to 50 to 60 percent by the year 2010 [p. 100]. This is due in part to economic advantages and a host of incentive programs, including the 1985 Food Security Act [National Research Council, p. 162].

Low-input sustainable agriculture (LISA). A collection of management systems currently receiving considerable attention is low-input sustainable agriculture (LISA); it has been identified more or less synonymously (in the same class) with "alternative agriculture," "organic farming," and "regenerative agriculture" [Buttel, et. al], although there are specific differences [Lockeretz; Crosson 1989; Madden]. While LISA system components and requirements differ by geography and farmer philosophy, a definition used much in the literature is from the U.S. Department of Agriculture:

> "Organic farming is a production system which avoids or largely excludes the use of synthetically compounded fertilizers, pesticides, growth regulators, and livestock feed additives. To the maximum extent feasible, organic farming systems rely upon crop rotations, crop residues, animal manures, legumes, green manures, off-farm organic wastes, mechanical cultivation, mineral-bearing rocks, and aspects of biological pest control to maintain soil productivity and tilth, to supply plant nutrients, and to control insects, weeds, and other pests." [p. xii]

A contemporary definition of lower-input/sustainable agriculture is:

> "Integrated systems of agricultural production that are less dependent on high inputs of energy and synthetic chemicals, and more dependent on intensive management than conventional monocultural systems. These lower-input sustainable systems maintain or only slightly decrease productivity, maintain or increase net income for the farmer, and are ecologically desirable and protective of the environment." [Edwards, p. 148]

The National Research Council simply describes alternative agriculture as "a systems approach to farming that is more responsive to natural cycles and biological interactions than conventional farming methods" [p. 135].

The interest in LISA practices relates to many of the current methods of soil and crop management practiced by organic farmers, which have been cited as best management practices for controlling soil erosion, minimizing water pollution, and conserving energy [USDA, p. xiv]. The shallow tillage used by organic farmers provides for better water conservation than moldboard plow (though conservation tillage and no-till are even better), the sod crops used in many organic rotations help initial water infiltration, and the additional organic matter added is helpful for infiltration [p. 58].

Many of the features of low-input sustainable agriculture are inherent in or part of conventional farming enterprises. However, the combination of most or all of these represent "alternative agriculture" systems as outlined by the National Research Council [p. 137]:

* Crop rotations that mitigate pest problems, increase available soil nitrogen and reduce need for synthetic fertilizers, and reduce soil erosion.
* Integrated pest management (IPM).
* Soil conserving tillage.
* Genetic improvement of crops to resist pests and diseases and to use nutrients more effectively.

Crop rotations provide many well-documented economic and environmental benefits to agricultural producers [Helmers, et al.; Domanico, et al.]. The rotational effect has been found to increase yields of crops beyond yields obtained under continuous cropping, primarily as a result of increased soil moisture, pest control, and availability of nutrients [National Research Council, p. 138-39]. Pest control is generally considered the greatest benefit of rotations, but nitrogen fixation by leguminous crops can also add nitrogen to the soil, reducing the need for additional fertilizers [Papendick, et al., p. 21].

Rotations have disadvantages, however. When rotations involve hay crops, on-farm livestock or local hay markets are generally necessary to make hay production profitable.

Even so, a leguminous hay would probably have a lower market value than the crop it replaced. The use of legumes as sources of nitrogen for grain crops requires greater management ability from farmers to synchronize supplies with uptake needs of the grain crops [Doran, et al.]. Current government subsidies and requirements for federal program participation weigh against adoption of rotations in many instances [National Research Council, p. 141; Goldstein and Young].

*B.2 Best Management Practices.*

In their efforts to educate farmers on techniques for controlling soil erosion, the Soil Conservation Service has relied on the concept of Best Management Practices (BMP). The Best Management Practice is defined as:

> "A practice or combination of practices that are determined by a state or designated areawide planning agency to be the most effective and practicable (including technological, economic, and institutional considerations) means of controlling point and nonpoint pollutants at levels compatible with environmental quality goals." [Soil Conservation Society of America]

However, what constitutes a "Best Management Practice" is dynamic, subject to interpretation, and often requires the judgment of agency personnel. Its broad definition, however, prevents a clear and definitive analysis of BMPs for policy. A practice may be "best" in an engineering sense for minimizing loss of chemicals, but not in an economic sense [Crutchfield, et al.]. From a policy standpoint, "best" is difficult to evaluate, as it depends on whether it improves resource allocation: "Best for whom? For what purpose? At what scale?" [L. Christensen, p. 39].

Section 208 of the 1972 Clean Water Act provided for a BMP incentive program for farmers, but the legal requirement has not yet been successfully adopted. According to Duttweiler and Nicholson, federal subsidies

> "...seem to be losing favor both philosophically and financially....Society continues to rely implicitly on farmers' stewardship of natural resources and their enlightened self-interest in conserving land and water for future agricultural production, with the costs of water quality protection being borne by the public through the marketplace for food and fiber." [p. 12]

The incorporation of general procedures and goals for achieving profitability while protecting the resource has been considered in a number of economic studies of the selection and evaluation of BMPs. Their evaluation, however, has traditionally focused on a partial-budgeting approach, that of comparing costs of operation only. There is a need to consider the perceived yield impacts and risks of new technologies [L. Christensen, p. 48].

What constitutes a BMP may depend upon local circumstances, but particular systems almost always fit the criteria for a BMP. These include conservation, reduced, and no-tillage; low-input or sustainable agriculture systems; and nitrogen management techniques.

It should be noted that in-stream management may supercede the need for BMPs. In-stream management involves riparian zone improvement or coordinated cleanup programs to minimize the damage to water courses. It has the advantage of flexibility, where approaches to cleanup can be changed if water quality goals are not met. One disadvantage of in-stream management "is that it requires much closer coordination between all parties involved in defining water uses and the management alternatives and goals. The higher costs of in-stream water quality management approach make it best suited to streams with valuable uses or important management problems" [L. Christensen, p. 40].

**C. Institutional dimensions.**

*C.1 Federal government.*

Federal involvement in the environmental effects of agriculture stems from the Soil Conservation and Domestic Allotment Act of 1936 which established the Soil Conservation Service within the U.S. Department of Agriculture. The support for the act demonstrated the willingness of society to pay farmers to shift from erosion-prone crops to soil-conserving uses which benefited the public as a whole, although the intent of the act was one of productivity enhancement rather than environmental control. Its success and popularity among farmers at the time was linked to the relative demand and prices of soil conserving crops to those of crops prone to erosion, which were in surplus. Since the 1940's, conservation programs have done better in times of depressed prices and surpluses and worse in periods of strong prices and expanding production [National Research Council, p. 79].

Growing environmental awareness in the sixties and early seventies culminated in passage of the Clean Water Act (Federal Water Pollution Control Act of 1972) (P.L. 92-500). The act's objective was to restore and maintain the chemical, physical, and biological integrity of the nation's waters, but it was left to individual states to prevent, reduce, and eliminate pollution and to plan the development and use of its land and water resources. Section 208 of the law provided for a cooperative effort between EPA and USDA through a "Rural Clean Water Program," and authorized federal funds for farmers who installed Best Management Practices [Duttweiler and Nicholson, p. 10].

Events of the 1970's through the mid-1980's combined to bring about greater public awareness of agriculture's environmental effects and to shape legislation. After decades of decline, harvested acreage increased by 60 million acres from 1972 to 1981 [American Agricultural Economics Association, p. 2]. As a result of that expansion, soil erosion increased significantly as more marginal and erodible lands were brought into production. Fertilizer and pesticide use increased in total volume and per acre. Price and income support aspects of federal farm programs have dominated environmental and conservation considerations. Finally, there were no policies in place to slow the conversion of wetlands or highly erodible grasslands to cultivated crops [National Research Council, p. 79].

The culmination of these perceived problems and cross-purposes was the Food Security Act of 1985 (P.L. 99-198). Its so-called "sodbuster" and "swampbuster" provisions denied program benefits to farmers who plowed highly erodible land without a conservation plan, or who drained or converted certain wetlands to cultivated crops. In addition, the Conservation Reserve Program (CRP) was implemented to pay farmers to take their most highly erodible land out of production; as of February 1988, 25.5 million acres had been idled [National Research Council, p. 79]. Finally, the 1985 FSA feature of conservation compliance required farmers to comply with conservation measures and implement plans to remain eligible for any government program.

It is noteworthy that the 1985 FSA did not address water quality specifically; the act was concerned with lands vulnerable to soil erosion (often marginal lands), rather than to regions where water quality is a problem (such as highly populated areas). It is expected that the 1990 farm bill will give significant consideration to surface and ground water quality. The Soil Conservation Service has already changed its mission to give equal emphasis to water quality and soil erosion [Thomas].

Amendments to the 1987 Clean Water Act required states to report their principal non-point sources of water pollution and programs for mitigation. The act, however, did not require implementation of measures to reduce non-point source pollution of surface waters.

An important principle underlying the federal policy towards soil conservation and water quality had been voluntary compliance or participation rather than mandatory controls or regulations. It had historically relied on free technical assistance, cost sharing funds, and commodity programs that retain an option for involvement. Such a focus suggests farmers had implicit property rights to soil resources, and otherwise had to be persuaded or bribed by other users (a role assumed by the federal government) to curtail polluting activities.

In recent years legislative actions of Congress have shifted emphasis from subsidy and education programs towards a mixture of subsidy and mandatory policies, implying a basic redefinition of property rights relative to use of the soil resource. The desire to reduce soil erosion as a non-point source of water pollution has increased at least the potential for further use of regulations [Hughes and Butcher]. However, the National Research Council concludes that "incentives integrated into agricultural conservation and commodity programs will likely remain the most effective way to reduce surface water pollution from agricultural sources, in lieu of further amendments to the Clean Water Act or regulations promulgated under the act" [National Research Council, p. 104].

*C.2 State of Oregon.*

States have been reluctant to impose environmental regulations on farmers that exceed those at the federal level. Legislators are generally hesitant to put their state's agricultural industry at a comparative disadvantage. A review of water-related bills from the two most recent sessions of the Oregon State Legislature suggests Oregon, for the most part, is in concurrence with other states.

Most water bills introduced in these sessions addressed quantity and allocation issues, but there was also interest in legislation relating to quality and definition of public water (property) rights. In 1987, bills were introduced to authorize a state-wide ground water survey (HB 3291), prohibit the discharge of chemicals known to cause cancer or birth defects into drinking water (SB 975), and enact a ground water and drinking water protection program (SB 981). This last one would have required the Director of Agriculture to determine the likelihood of chemical contaminations and establish a monitoring program, based on standards established by the Department of Environmental Quality. These bills failed to become law. However, bills identifying minimum stream flows for recreational uses (SB 136) and defining public water rights (SB 140) were passed. A subsidy bill for erosion and conservation projects (SB 2887) did not.

The 1989 session saw bills introduced establishing a state-wide ground water protection program (SB 423), establishing funding for ground water protection (HB 2176), and requiring the Health Department to protect the state's municipal watersheds from harmful uses (HB 2507). None managed to make it past the committee level.

In summary, the state has conceded to the federal government the determination of standards and regulations for water quality as it pertains to agriculture. There are no regulatory programs in place to prevent chemicals from reaching ground water, though chemical use can be banned to control contamination [Oregon Department of Environmental Quality, p. 24]. While there is some interest at the state level for tighter controls and/or enforcement, it has been insufficient to change current law.

**D. Economic dimensions.**

The control of agricultural runoff from farmlands is a bioeconomic problem affecting many interests. The decision facing policy makers is how to solve the environmental problems associated with agricultural activity without significantly harming the industry. The economic consequences of externalities and mechanisms for correction of market failure are defined and discussed in this section.

*D.1 Externalities.*

The concepts of common property resource, public good, and externality are tied closely to discussions of market failure. Given potential ambiguity concerning these concepts, they are presented and discussed in this section, with particular relevance to agricultural pollution.

Gordon first developed the concept of the "common property resource" as an unowned resource (a fishery), with property rights being nonexclusive. (That is, no mechanism exists to bar access to the resource.) This contrasts with the use of the term as property that is held collectively or in common. For property held in common, ownership is jointly held and rules are established to limit exploitation of the resource. Individual property rights are not assigned due to the high cost of exclusion [Randall, p. 133]. (Consider, for example, the difficulty in assigning exclusive property rights to ambient air or particular schools of fish in the open sea.)

In contrast, most definitions of "public good" consider aspects of nonexclusiveness or nonrivalry, or both. Nonexclusion is as defined above, and nonrivalry refers to the notion that a good may be consumed by some without diminishing availability to others. The confusion in the literature regarding this term lies in identifying which characteristics are necessary to render a good or commodity "public." Replacing the "public" term by nonexclusiveness and nonrivalry has been suggested by Randall [p. 134].

Finally, externalities are defined by Baumol and Oates as existing

> "whenever some individual's (say A's) utility or production relationships include real (that is, nonmonetary) variables, whose values are chosen by others without particular attention to the effects on A's welfare" [p. 17];

more particularly, it is an output or effect of the production process for a commodity, whose cost is not borne by the producer, and which is not sold in the marketplace. There is no signaling or incentive scheme in which the producer is forced to account for the interdependence of his actions with another individual's utility in his or her decision making [Campbell, p. 57].

A second condition is required for an externality to result in inefficiency:

> "The decision maker, whose activity affects others' utility levels or enters their production functions, does not receive (pay) in compensation for this activity an amount equal in value to the resulting benefits (or costs) to others." [p. 17]

Externalities can generally be classed according to their excludability and depletable (rivalry) characteristics. The exclusion requirement is often used to distinguish private, tradeable goods from nonrival public goods[2]. However, whether goods are depletable (one's consumption decreases availability for others) or undepletable (one's consumption does not affect another's consumption, except for congestion) may be a clearer distinction of private and public goods [Baumol and Oates,

---

[2] Public goods can be classed as both nonexclusive (such as national defense) as well as exclusive (such as toll roads).

p. 19]. Depletable externalities arise from a number of causes. In practice their most common source is institutional barriers which prevent effective assignment of property rights.

A decentralized market mechanism can operate only under a well-defined system of property rights which allows agents to use a factor or consume goods for which they have paid, and excludes them from consuming an unwanted factor or commodity without compensation [Boadway and Bruce, p. 110]. However, for many factors or goods, it is prohibitively expensive to assign and/or enforce property rights, hence they are termed "common property." Common property resources are subject to externalities when an agent cannot exact the cost of resource use by another. An example of an externality resulting from the existence of common property is the case of factories which release pollutants into the air.

Externalities result in inefficiency because resources are not allocated according to their true relative prices, and some commodities (for example, from a polluter) are overproduced and others (community health) are underproduced. An inefficiency or misallocation of resources resulting from the presence of a depletable externality can be corrected by charging a price (Pigouvian tax) equal to the marginal social cost (benefit), which places an appropriate price on the resource [Baumol and Oates, p. 23]. For an undepletable resource the price system simply fails to operate at all. Any nonzero price for the externality produces an inefficiency; the optimal price to suppliers of a detrimental externality is negative (a charge for social damage). However, the optimal price to consumers is zero, because an increase in the number of consumers of externalities has neither costs nor benefits to others [Baumol and Oates, p. 24]. Thus, the price system is inherently incapable of dealing with such cases.

An optimal resource allocation mechanism in the case of externalities suggested by Baumol and Oates, Maler, and others is a tax on or subsidy to the supplier of the associated good to serve as the required nonzero price. However, compensation and taxing of the victims of the externality is inappropriate. At a zero price (tax) the victim bears full social cost of the externality; a compensation provides incentive for absorbing the externality. It is appropriate for tax revenues collected from the suppliers to be placed in the public treasury so that external effect charges on consumers no longer exist.

Agricultural externalities can be depletable and beneficial (topsoil and nutrients deposited on another farmer's land), depletable and detrimental (sediment on private land which smothers young crops), or undepletable and detrimental (soil and chemicals deposited in public waterways). Those of most concern (and which are considered here) are undepletable and detrimental, with multiple suppliers and multiple victims.

Crosson and Brubaker [p. 136] discuss in detail why the market may undervalue land in terms of soil erosion. Their reasons include:

(1) a general lack of knowledge by farmers of the productivity effects of erosion, combined with an overestimate of future supply of land;

(2) a misjudgment by the market of the strength of forces which affect future demand for food and fiber, and thus, underestimates future prices;

(3) a market overestimate of the rate of emergence of economical land-saving technologies;

(4) the social cost of investments in control which is less than private costs; and

(5) the market typically assigns a lesser weight to the maintenance of land productivity as a hedge against future demand for food and fiber than does society.

The first three reasons arise from incomplete information in the market for agricultural land. The fourth reason is due to comparative social versus private rates of interest/discount: the lower rate for society is due to government risk of default being lower than private. The fifth and final reason is due to society's interest in providing for future uses of land, which market forces tend to ignore. This last argument is considered by the authors as the "most persuasive," since in their opinion society assigns higher value to the annual net benefits of these conservation practices than does the market [p. 138].

*D.2 Correction of market failure.*

Coase maintained that government intervention in the correction of externalities was unnecessary and undesirable when certain conditions held, among them the existence of well-defined property rights and a lack of transactions costs. The nature of NPS pollution as a nonexclusive and nonrival externality limits the potential for negotiation and thus suggests a need for regulation. Various measures may be considered for correcting market failures.

Taxes. The Pigouvian tax is a proper and appropriate theoretical measure for correcting externalities under certain conditions, as discussed earlier. In practice, however, taxes require a multitude of information which are usually difficult to find or even approximate.

A condition of note (and particularly relevant to this study) is where multiple activities yield one or more externalities. It is not possible to say in advance whether the optimal level of an activity is a Pareto improvement over its competitive level; in fact, due to interdependencies the problem is apt to be complex, requiring considerable information [Baumol and Oates, p. 96]. In the case of agricultural externalities, the correction of one problem (for example, surface water quality) may exacerbate another (ground water quality). In such situations where multiple targets exist, one approach is to apply simultaneously an equal number of instruments [Tinbergen, p. 27].

Standards. A flexible alternative mechanism to taxes is the selection of a set of standards representing "an acceptable environment". These are established (subjectively), preferably on the basis of scientific evaluation, and behave as constraints on activities. Corresponding to these standards could be charges or "prices" for the private use of resources, and could be selected so as to achieve specific standards. Thus, a financial incentive is provided the polluter for reducing discharges [Baumol and Oates, p. 137-38].

An important consideration with standards is the size of a unit over which the target or standard is measured. Standards usually take a form such as 10 milligrams per liter; whether the monitored unit is a cubic meter (thus, every meter must comply with the standard) or a hectare will influence both the cost of monitoring and the ability of the polluter to meet the standard. The larger the "bubble", the greater the flexibility for the polluter, and the better the chance of approaching optimality.

The presence of stochastic influences (such as highly irregular weather conditions) can lead the standard to be the least-cost method for improving social welfare. But standards should be used sparingly, as they can have severe producer consequences. In general, the standard is most appropriate when the existing situation imposes a high level of social costs and that these costs can be significantly reduced by feasible decreases in the levels of certain externality-generating activities [Baumol and Oates, p. 149].

Controls. The use of direct controls are not usually advocated by economists. Direct controls involve a directive to individual decision makers requiring them to set one or more output or input quantities at some specified levels or prohibiting them from exceeding (or falling short of) some specified levels [Baumol and Oates, p. 153]. Controls have the advantage of adjusting to the stochastic nature of many environmental problems, and they are generally inexpensive to implement [Baumol and Oates, p. 155-56]. However, direct controls are effective only when enforcement is possible.

*D.3 Control of NPS Externalities.*

Mechanisms to control NPS pollutants must remain effective under conditions where runoff from farms cannot always be monitored. Therefore, taxes on inputs (such as nitrogen), or management practice standards (e.g., required use of a conserving tillage) have been considered and in some cases implemented. When the runoff is observable (as is the case with soil erosion), taxes applied directly to the externality may be effective.

The choice of instrument (or combination of instruments) to correct NPS pollution relies not only the instrument's effectiveness in achieving the goal or objective, but also on its implementation and monitoring costs; in fact, information requirements and policy costs may be the primary choice determinant [Baumol and Oates, p. 155; Shortle and Dunn]. It is on this basis that direct controls have achieved such favor with policy makers, as it is relatively easy to catch violators. Input taxes, too, are easy to administer despite their "broad-brush" approach to solving pollution problems.

Pigouvian taxes applied to NPS pollution (moreso than with point source pollution) run into difficulty because monitoring may not be feasible or even possible. For some types of pollutants (for example, soil sediment) monitoring of a farm or set of farm fields which drain into a stream channel may be feasible. However, groundwater contamination or even surface water pollution is unlikely to be traceable. Both taxes and standards also require considerable information (about damage costs, concentrations of pollutants, "acceptable" levels and ranges, etc.), adding to their implementation problems. In general, a combination of these mechanisms (taxes, standards, and controls) may be necessary to bring about effective control of nonpoint source externalities.

# III. APPROACH AND PROCEDURES IN ASSESSING ON-FARM POLLUTION CONTROL OPTIONS

Most assessments of the economic consequences of environmental policy on agriculture typically assume a scenario of single crops under average weather conditions, i.e., a single product production function. In some locations, such as the Corn Belt [Pierce, et al.], the Cotton Belt [Yoo and Touchton], or the Palouse [Burt], this is appropriate since monoculture or short rotation management systems dominate. However, in many settings farmers face options about crop rotation, tillage, management, and fertilization, which when combined with government program compliance and regulations, require a more complex framework to assess profit and environmental trade-offs. The approach used in this study reflects some of these on-farm options in the context of their implications for one or more environmental externalities, and in the selection of optimal production sets.

This chapter outlines the procedures used in evaluating the effectiveness, efficiency and income effects of policies for reducing agricultural externalities in the Willamette Valley. An overview of the general framework for the analysis is presented first. This is followed by a description of the biophysical crop simulation model (Erosion-Productivity Impact Calculator; EPIC) used in the analysis, including a discussion of its application to the

Willamette Valley. A discussion of the GAMS-based (General Algebraic Modeling System) linear programming optimization routine follows. The linear-programming discussion includes the selection of representative farms. This is followed by a discussion of the characteristics of the Willamette Valley in terms of soils, crops, and other aspects of the natural and economic environment. The next section in this chapter outlines data sources and assumptions. The last section presents the environmental policy options tested in the optimization framework.

**A. General procedure.**

The analysis of farm-level policies for the control of nonpoint source pollution proceeds in a general two-part simulation involving (1) an environmental parameter component and (2) an economic optimization routine. Specifically, this process can be broken down into a series of steps:

1) identifying important or characteristic Willamette Valley soils and crops;

2) building associated rotation-tillage practice-soil-slope combinations, representing options faced by farmers, for use in both the EPIC simulator and the GAMS model;

3) running computer simulations with EPIC of these combinations for a sufficient length of time (25 years) to produce expected annual levels of crop and environmental outputs;

4) creating representative farms containing appropriate soils and crop rotation options for the associated EPIC outputs;

5) selecting profit maximizing crop rotations using GAMS; and

6) optimizing the linear programming models under constraints of imposed charges, standards, and controls.

The process centers around the EPIC simulator and the GAMS model (figure III-1). EPIC endogenously maintains a crop simulator and data base of parameters for crops and farm operations (including tillage practices); it also contains nutrient flow, hydrology, and weather simulation features. Inputs to EPIC include locational characteristics (soil and climate), and farm specific systems. This latter input set is the rotation to be tested, and requires information on management (farm operations and dates), irrigation, fertilizer applications, tillage practices, and crops in rotation. Outputs from EPIC are annual yields (averaged over the simulation period) and nutrient flow levels.

A linear program for each of the representative farms is modeled using GAMS. Unlike EPIC, all characteristics of the farm must be supplied exogenously to the linear model. Environmental outputs (nutrient flow levels and erosion) and yields from EPIC are incorporated as coefficients. Farm specific behavior (relating to rotations and tillage practice combinations) are used in forming both activities and constraints. Environmental restrictions and regulations are also imposed when conducting policy tests.

Farm-level data from direct farm surveys, published

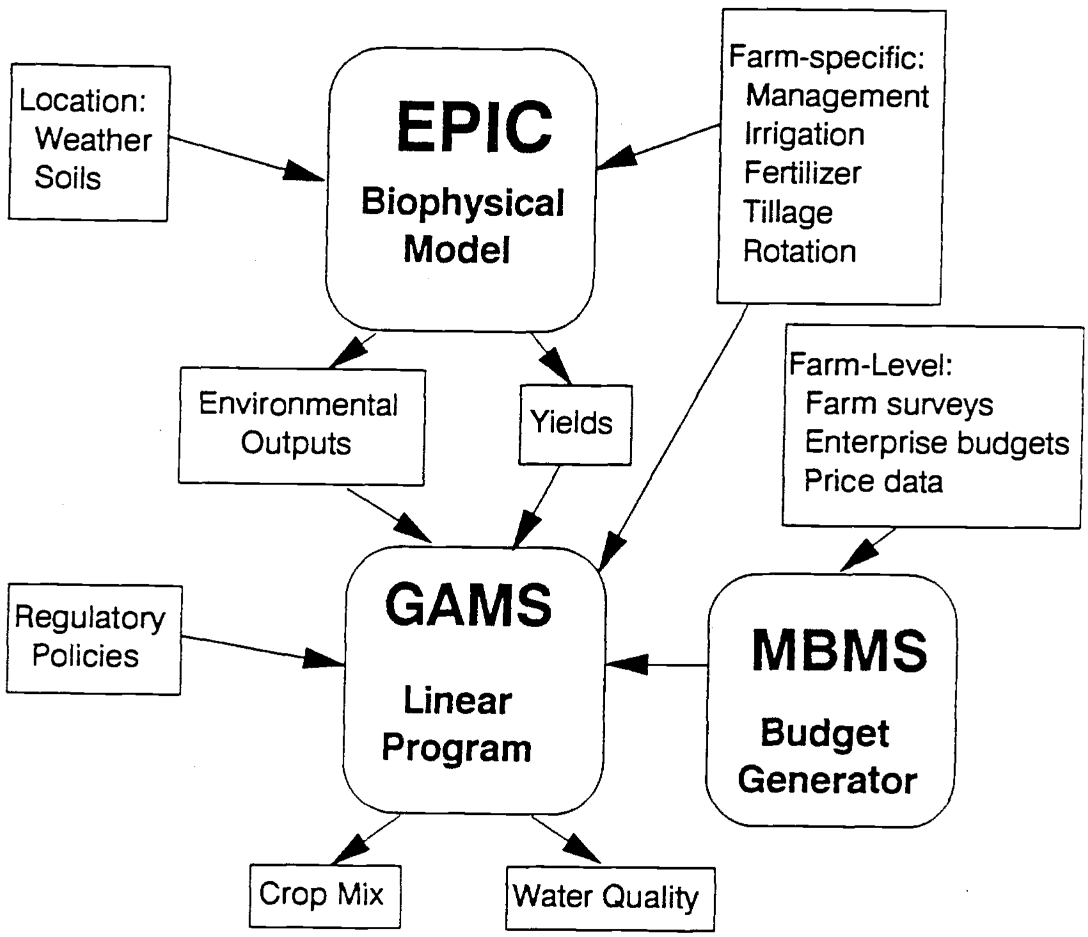



Figure III-1. Schematic flow diagram of assessment framework.

enterprise budgets, and market prices are used to generate crop enterprise budgets for economic portions of the farm model. An intermediate step involved processing the budgets using MBMS (Microcomputer Budget Management System) [McGrann, et al.]. This computer program computes machinery complements to be used in an accurate accounting of farm operation costs.

The output of each of the GAMS models is an optimal (profit maximizing) crop mix (including rotation and tillage practices), and an associated set of environmental outflows. The changes in profit, crop mix, and physical outputs recorded between the unrestricted (unregulated) farm and that farm under various imposed policies provides a measure of policy effectiveness.

## B. Modeling the biophysical system: EPIC.

### *B.1 Model description.*

An inherent feature of nonpoint sources of pollution is that flows cannot be monitored with reasonable accuracy or at reasonable cost. Another is that nonpoint pollution is stochastic in nature, influenced strongly by weather processes. As a result, policy analysts increasingly rely on models which estimate or predict environmental flows and simulate agronomic processes. These models help to reduce uncertainty associated with developing policies for curtailing nonpoint source pollution. While such models will never be perfect substitutes for monitoring of actual flows, they can serve as important tools for analysis [Shortle and Dunn].

One such model used widely in agricultural applications is the Erosion-Productivity Impact Calculator (EPIC), developed by U.S.D.A. Agricultural Research Service [Williams, et al. 1989]. EPIC has been used in a variety of settings, including the 1985 Resource Conservation Act analysis determining the status of soil and water resources in the U.S [Williams, et al. 1984], and the American Agricultural Economics Association Soil Conservation Policy Task Force [A.A.E.A.]. It has been tested on more than 150 sites in the continental U.S. (including Oregon), with "satisfactory" and "promising" results [Williams, et al. 1984, p. 141]. Further details on validation are provided in the next section.

EPIC is an event-based computer simulation model designed to determine the relationship between soil erosion and soil productivity, as well as nutrient (nitrogen and phosphorus) processes throughout the United States. The physically based components for simulating erosion, plant growth, and related processes include hydrology, weather simulation, erosion-simulation, nutrient cycling, plant growth, tillage, and soil temperature [Williams, et al. 1989, p. 1].

*B.2 Selection and validation.*

A model's accuracy in predicting outcomes under a variety of circumstances is critical to establishing confidence in its appropriateness for a bioeconomic assessment. This section provides the rationale for choosing the EPIC model to simulate environmental and agronomic effects of pollution control.

A number of sophisticated, state-of-the-art computer simulation models have been developed and revised for estimating soil erosion and for modeling nitrogen transformations, including CREAMS [Knisel and Foster], Hydrologic Simulation Program - Fortran (HSPF), and AGNPS [Young, et al.]. While each has been validated to some extent in various parts of the country, to the author's knowledge none have been explicitly tested for accuracy under conditions found in the maritime region of the Pacific Northwest. Model selection therefore depends upon: (1) the logical consistency of each model with regional conditions, and (2) accuracy of empirical tests under related parameters.

The choice of EPIC is based on of its relative strengths in simulation, and its ability to perform reasonably well under Oregon conditions. EPIC maintains a comprehensive collection of soil, climatic, cropping, fertilization, and tillage management data, much of which may be left to default values or modified. A daily simulator generates random weather events (based on long-term climatic features of the location), and imposes these externally on the land resource. The EPIC computer package includes data base files for weather (including Salem, Oregon) and 737 U.S. soils (including Dayton, Jory, and Woodburn soils). The comprehensive input requirements, interaction of components, and the detailed output provided by EPIC allows the model to fulfill the first criterion of consistency with regional conditions.

A difficulty inherent in most biophysical models is the limited number of empirical studies with which to gauge the model's performance. Thus, it is often difficult to judge the predictability and accuracy of a given model. General correctness can be judged by knowledgeable individuals familiar both with the processes being modeled, and the geographic region. This method was used to assess the empirical accuracy of the EPIC model. Characteristics of the empirical setting are discussed later in section D.

Simulation runs were generated on a trial basis for wheat, sweet corn, and grass seed on Chehalis, Wapato, Woodburn, Amity, Dayton, Jory, and Nekia soil representations. Yields and environmental outputs (erosion, and nitrogen and nitrate flows) were estimated. A discussion of these results with Neil Christensen and John Hart, soil scientists at Oregon State University, concluded:

1) Nitrate flows from the root zone were comparable and generally acceptable for wheat and sweet corn on Woodburn and Amity soils, and for wheat on Jory soils.

2) Though no comprehensive or comparative studies are known to have been conducted on the nitrate flows from grass seed production, results from all soils were considered reasonable.

3) On Chehalis soils (well-drained, river-bottom lands), yields for grain crops were too low, and nitrate leachate levels too high. This probably reflects an inability of EPIC to sufficiently account for the water-holding capacity of Chehalis soil.

4) Soil erosion rates from crop production on Nekia soils were excessive. An inadequate representation by EPIC of the true nature of the Nekia soil, from the data available, was assumed to be reason.

As a result of this discussion, it was decided that (1) the importance of Chehalis soils in agricultural production in the valley warrants its continued inclusion in the analysis, with the expectation that nitrate flows would be "overestimates;" and (2) the Nekia representation would be eliminated, but that Jory, which is similar to Nekia and Bellpine soils [Huddleston], would represent Nekia and Bellpine soils in the foothill farms. The Jory simulation results probably underestimate erosion and runoff for Nekia and Bellpine soils.

*B.3 Generation of parameters.*

Representative farms (defined in section C) were determined, and eleven associated soil and land slope combinations were selected. Each soil-slope set implicitly determined the crop enterprises and, subsequently, crop rotations (including monocultures) that could be considered. A crop rotation is defined here as a collection of enterprises in a regular production cycle. Thus, a soil-slope-rotation combination became one base run on EPIC. In the restriction-free condition, this amounted to 164 runs on EPIC (table III-1).

A run on EPIC is a twenty-five year simulation (on a daily basis) of crop rotations on soil-slope sets. The weather events are generated randomly, but uniformly on all soil-slope-crop rotation combinations. Average outflows of erosion, organic N in sediment, $NO_3$ runoff, P runoff, and $NO_3$ leachate are recorded, along with average yields.

Additional runs were necessary on rotations for which there was a 15%, 25%, and 50% reduction of applied nitrogen fertilizer. Some crops were also run with the fall fertilizer eliminated.

Erosion. Erosion rates are computed in EPIC using the Modified Universal Soil Loss Equation (MUSLE):

$$Y = x\ (K)(CE)(PE)(LS)$$

$$x = 11.8\ (Q * p)^{0.56}$$

where Y is the sediment yield in tons/acre, K is the soil erodibility factor, CE is the crop management factor, PE is the erosion control practice factor, LS is the slope length and steepness factor, Q is the runoff volume in cubic feet, and p is the peak runoff rate in cubic feet per second (for more information, see Williams, et al.). MUSLE is considered superior to the standard Universal Soil Loss Equation because MUSLE considers runoff volume and rate in its equation. Conditions of low-intensity, high

Table III-1. Crop rotation-tillage practice combinations on soils[1] and slopes, modeled on EPIC, using crop growth parameters as defined.

| - CROP ROTATIONS - | - MANAGEMENT - | SOIL: Cheh | Wap | --- Woodburn --- 1% | 6% | 10% | 15% | Am | Dayt | --- Jory ---- 5% | 10% | 15% | Modeled using EPIC crop parameters |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wheat | Conventional | x | x | x | x | x | x | x | x | x | x | x | Wheat |
| Wheat | Reduced tillage | x | x | x | x | x | x | x | x | x | x | x | Wheat |
| Wheat | No-till | x | x | x | x | x | x | x | x | x | x | x | Wheat |
| Wheat | - No fall fert. | x | | x | x | x | x | x | | | | | Wheat |
| Wheat/grass seed | Conv/Conv | x | x | x | x | | | x | x | x | x | | Wheat/Winter pasture |
| Wheat/grass seed | Conv/No-till | | x | x | x | x | x | x | x | x | x | | Wheat/Winter pasture |
| Wheat/Oats | Conv/Conv | | | x | x | x | x | x | x | x | x | x | Wheat/Oats |
| Wheat/Oats | No-Till/Conv | | | x | x | x | x | x | x | x | x | x | Wheat/Oats |
| Wheat/Oats/Clover | Conv/Conv | | | x | x | x | x | x | x | x | x | x | Wheat/Oats/Clover |
| Wheat/Aus. Peas | Conv/Conv | x | | x | x | x | x | x | | | | | Wheat/Austrian Peas |
| Wheat/Clover | Conv/Conv | | | x | x | | | x | | x | x | x | Wheat/Clover |
| Spring Oats | Conventional | | | x | | | | x | | x | | | Oats |
| Annual Ryegrass | Conventional | x | x | | | | | x | x | | | | Winter pasture |
| Annual Ryegrass | - 75% fert.[2] | | x | | | | | x | x | | | | Winter pasture |
| Annual Ryegrass | - 50% fert. | | x | | | | | x | x | | | | Winter pasture |
| Annual Ryegrass | - No fall fert. | | x | | | | | x | x | | | | Winter pasture |
| Annual Ryegrass | No-till | x | x | | | | | x | x | | | | Winter pasture |
| Annual Ryegrass | - 75% fert. | | x | | | | | x | x | | | | Winter pasture |
| Annual Ryegrass | - 50% fert. | | x | | | | | x | x | | | | Winter pasture |
| Annual Ryegrass | - No fall fert. | | x | | | | | x | x | | | | Winter pasture |
| P. Grass (5)/Wheat | Conv/Conv | x | x | x | x | x | x | x | x | x | x | x | Winter pasture/Wheat |
| P. Grass (5)[3] | Conventional | x | x | x | x | x | x | x | x | x | x | x | Winter pasture |
| P. Grass (5) | - 75% fert. | x | x | x | x | x | x | x | x | x | x | x | Winter pasture |
| P. Grass (5) | - 50% fert. | x | x | x | x | x | x | x | x | x | x | x | Winter pasture |
| P. Grass (5) | - No fall fert. | x | x | x | x | x | x | x | x | x | x | x | Winter pasture |
| Dryland past. & hay | | x | x | x | x | x | x | x | x | x | x | x | Winter pasture |
| Irrig. past. & hay | | x | x | x | x | x | | x | | | | | Winter pasture |
| Unimproved range | | | | | | | | | x | x | x | x | Winter pasture |
| Continuous corn | Conventional | x | | x | x | | | x | | | | | Corn |
| Continuous corn | - 75% fert. | x | | x | x | | | x | | | | | Corn |
| Continuous corn | - 50% fert. | x | | x | x | | | x | | | | | Corn |
| Corn/Snap beans | Conventional | x | | x | x | | | x | | | | | Corn/Corn |
| Corn/Snap beans | - 75% fert | x | | x | x | | | x | | | | | Corn/Corn |
| Corn/Snap beans | - 50% fert | x | | x | x | | | x | | | | | Corn/Corn |
| Corn/Beans/Wheat | w/winter cover | x | | x | x | | | x | | | | | Corn/Corn/Wheat/Clover |
| Corn/Beans/Wheat | - 75% fert | x | | x | x | | | x | | | | | Corn/Corn/Wheat/Clover |
| Corn/Beans/Wheat | - 50% fert | x | | x | x | | | x | | | | | Corn/Corn/Wheat/Clover |
| Corn/Clover cover | Conventional | x | | x | x | | | x | | | | | Corn/Clover |
| Corn/Clover cover | - 75% fert | x | | x | x | | | x | | | | | Corn/Clover |
| Corn/Clover cover | - 50% fert | x | | x | x | | | x | | | | | Corn/Clover |
| Corn/Aust. Peas | Conventional | x | | | | | | x | | | | | Corn/Austrian Peas |
| Christmas trees | | | | | | | | | | x | x | x | Pine trees |

[1] Soils are Chehalis, Wapato, Woodburn, Amity, Dayton, and Jory.
[2] "75% fert" and "50% fert" refer to 75% and 50% applied fertilizer.
[3] Values in parentheses are years of rotation in that perennial crop.

precipitation as found in the Willamette Valley render the USLE unsuitable in effectively measuring erosion [Istock, et al.; N. Christensen].

## C. Translating physical effects into farm-level economic consequences.

*C.1 Model description.*

The Willamette Valley is a region of diversified agriculture, with no single crop- or farm-type dominant. However, five farm-types were defined to represent the major combinations of crops, soil types, and geographic subregion within the valley. The farms were selected to consider the widest range of conditions and options facing commercial farmers of the Willamette Valley. Farm descriptions are listed below[3].

(1) Well-drained bottomland

| | |
|---|---|
| ACREAGE | 450 acres, all Chehalis (1% slope) |
| MAIN CROP | Vegetables |
| LOCATION | Central valley |
| SOILS | Chehalis, Cloquato |
| NOTES | Leachate is probably overestimated; periodic winter flooding not considered, so runoff is probably underestimated |

(2) Poorly-drained bottomland

| | |
|---|---|
| ACREAGE | 200 acres, all Wapato (1% slope) |
| MAIN CROP | Grass seed and pasture/hay |
| LOCATION | North valley |
| SOILS | Wapato |
| NOTES | Periodic winter flooding not considered, so runoff may be underestimated |

[3] Underlined names are the soils modeled on EPIC; they are discussed in detail in section D.

(3) Well-drained terrace land

| | |
|---|---|
| ACREAGE | 500 acres, all Woodburn with 373 acres 1% slope, 80 acres 6% slope, 32 acres 10% slope, and 15 acres 15% slope |
| MAIN CROP | Wheat, vegetables |
| LOCATION | Central valley |
| SOILS | Woodburn, Willamette, Coburg, Malabon |
| NOTES | Represents the largest land base in the valley |

(4) Poorly-drained terrace land

| | |
|---|---|
| ACREAGE | 1,000 acres, with 740 acres Dayton (1% slope) and 260 acres Amity (1% slope) |
| MAIN CROP | Grass seed |
| LOCATION | Southern valley |
| SOILS | Dayton, Amity, Concord |
| NOTES | Ten percent (26 acres) of Amity soil assumed tiled |

(5) Well-drained foothills

| | |
|---|---|
| ACREAGE | 400 acres, all Jory with 193 acres 5% slope, 128 acres 10% slope, and 79 acres 15% slope |
| MAIN CROP | Pasture |
| LOCATION | All valley foothill areas |
| SOILS | Jory, Bellpine, Nekia |
| NOTES | Erosion and leaching may be underestimates for shallower Bellpine and Nekia soils |

The economic behavior of the farms is simulated using a linear programming model for each farm, with an objective of profit maximization. The optimizer used is GAMS (General Algebraic Modeling System) [Brooke, et al.] which uses MINOS version 5.1 [Murtagh and Sanders]. GAMS has particular features which make it useful for large models. Equations and activities (variables) may be coded in blocks (for example, acreage limits or harvested crop products), which is logically consistent and allows for easy "debugging".

Considerable explanatory text may be included to ease in later refinement of the models. Adjustments and changed parameters (for policy option analysis) can also be applied to the main batch file and adopted instantaneously.

*C.2 Linear programming formulation.*

The five farm-types are cast as linear programming problems using input from the EPIC model simulation. The LP model form is identical for all five farms. A maximum profit plan is given by solving a problem with the following components.

$$\text{Max } \sum_i PRICE_i X_i - \sum_s EXPEND_s C_s - \sum_k LAND_k Z_k$$

subject to:

| | | | |
|---|---|---|---|
| $INP_{sj} Y_j = C_s$ | for all s | (enterprise input costs) |
| $YIELD_{ik} Z_k = X_i$ | for all i | (yield-to-product balance) |
| $ACRES_{rk} Z_k \leq S_r$ | for all r | (soil acreage limit) |
| $PROD_{jk} Z_k = Y_j$ | for all j | (enterprise-rotation bal.) |
| $ENV_{fk} Z_k = Q_f$ | for all f | (environmental outputs) |
| $MACH_{utj} Y_{ut} \leq T_{ut}$ | for all u,t | (enterprise-machine times) |

with activities:

- $X_i$ is quantity produced of crop i;
- $Y_j$ is acres of enterprise j;
- $Z_k$ is acres of rotation set k;
- $C_s$ is units of input s; and
- $Q_f$ is units of environmental output;

and coefficients:

- $PRICE_i$ is price of crop i;
- $EXPEND_s$ is per unit cost of input s;
- $LAND_k$ is rent for land used in rotation set k;
- $INP_{sj}$ is cost of input s for enterprise j;
- $YIELD_{ik}$ is yield of crop i in rotation k;
- $ACRES_{rk}$ is acres of soil r in rotation k;

$PROD_{jk}$ is acres of enterprise j in rotation k;
$ENV_{fk}$ is units of environmental output f in rotation k;
$MACH_{utj}$ is hours of machine u at time t of the crop year for enterprise j;

$S_r$ is acre limit of soil r;
$T_{ut}$ is hour limit for machine u at time t of the crop year;

i = {wheat, annual ryegrass seed, ... , pasture};
j = {conventional till wheat, no-till wheat, ... , irrigated pasture};
k = {continuous wheat, wheat-ryegrass, ... , seven-year pasture};
r = {Woodburn-1%, Woodburn-6%, ... , Dayton};
s = {fixed, variable, labor, machinery, NPK, nitrogen};
f = {erosion, Nloss, $NO_3$ runoff, perc-N, phos};
t = {March 1-31, April 1-15, ... , November 10-20};
u = {111 hp tractor, 165 hp tractor, 225 hp combine}.

The objective function is maximized, generating total revenue minus expenditure for inputs and land rent. The first constraint compiles input costs of enterprises (as production methods). The second links products (crops sold) with yields in rotation and management combinations. An acreage limitation is next, according to acres in rotation.

The fourth constraint accounts for environmental outputs, such as nitrate percolation and erosion, generated by crop rotations, giving farm level totals. The final set of constraints limits machinery usage by enterprise to hours available in pertinent time periods of the crop year.

The relationships and linkages of the linear programming model can also be seen when the general matrix form,

$$\begin{aligned} &\text{Max} \quad \mathbf{CX} \\ &\text{s.t.} \quad \mathbf{AX} \leq \mathbf{B} \end{aligned}$$

is decomposed into submatrices, as in table III-2.

Each of the five farm models contains relevant subsets of the listed components; for example, the riverbottom vegetable farm contains only Chehalis soils, and the foothill farm does not provide for irrigated crops or associated enterprises. The model ranges in size from 52 equations and 63 variables for the poorly-drained bottomland farm, to 81 equations and 176 variables for the well-drained terrace farm.

The distinction between enterprise sets and crop rotation sets is a key component of this formulation. Enterprise sets are defined in the usual way as the costs and operations associated with production of a single commodity. Rotation sets combine appropriate enterprises with soils and land slope, incorporating the interactive effects of crop rotations, as occurs in crop yields and environmental outputs.

*C.3 Sources and types of errors.*

The linking of the biophysical crop simulation model to a farm-level optimization model, and the representation of farm enterprises in a linear program, create potential sources of errors in the analysis. The types and sources of these errors are discussed in this section.

The choice set of crops, management systems, rotations,

Table III-2. Tableau form of general linear programming model.

| Crop Sales | Enter-prises | Soil-Rotations | Inputs | Environ. outputs | | |
|---|---|---|---|---|---|---|
| $C_1$ | | $-C_3$ | $-C_4$ | | MAXIMIZE | |
| | $A_{1,2}$ | | $-I$ | | $= 0$ | Input costs |
| $-I$ | | $A_{2,3}$ | | | $= 0$ | Yield-product balance |
| | | $A_{3,3}$ | | | $\leq B_3$ | Soil acreage limit |
| | $-I$ | $A_{4,3}$ | | | $= 0$ | Enterprise-rotation balance |
| | | $A_{5,3}$ | | $-I$ | $= 0$ | Environmental outputs |
| | $A_{6,2}$ | | | | $\leq B_6$ | Tractor 1 time |
| | $A_{7,2}$ | | | | $\leq B_7$ | Tractor 2 time |
| | $A_{8,2}$ | | | | $\leq B_8$ | Combine time |
| | $A_{9,2}$ | | | | $\leq B_9$ | Fescue limit |
| | $A_{10,2}$ | | | | $\leq B_{10}$ | Perennial ryegrass limit |
| | $A_{11,2}$ | | | | $\leq B_{11}$ | Vegetables limit |

and application levels of inputs is necessarily limited by the method of analysis selected for this dissertation. The EPIC runs are predetermined and fixed through a specified time horizon. The soil-slope-rotation combinations used in EPIC correspond directly to and define the activities used in the LP models. This use of discrete approximations for a (continuous) production possibilities frontier results in an underestimate of the true objective function value.

While the EPIC model effectively simulated production of commodities currently grown in the study region, it was not possible to expand the choice of crops or management systems to include crops or systems not currently in use. This was due to two reasons: (1) only those crops currently in production have a yield record for the purpose of validation; and (2) EPIC crop growth models are available for only a limited number of field crops which could be grown in the Willamette Valley.

## D. Problem setting: The Willamette Valley.

### *D.1 Location and farm characteristics.*

As mentioned in the Problem Statement of chapter I, the Willamette Valley of Oregon is an important agricultural area as well as the state's primary population base. Its climate, topography, diversity, and value of crops and population distribution creates some interesting resource use issues.

The Willamette Valley, encompassing nine counties in western Oregon, lies between the Cascade and Coast Range Mountains (see figure III-2). The valley is 125 miles long, stretching from Cottage Grove on the south northward to Portland, and as much as forty miles wide. The climate is under a modified maritime influence, due to the valley's proximity to the Pacific Ocean. Precipitation ranges from just under 40 inches annually on the valley floor, to sixty inches in the foothills, and over one hundred inches in the mountains. Nearly all precipitation in the valley falls in the form of rain, with 70 percent of the annual total occurring November through March (figure III-3). These months are characterized by persistent clouds, occasional light rain, and very low evaporation rates [Ruffner and Bair; National Oceanographic and Atmospheric Administration]. Mild temperatures relatively free of extremes, a long growing season, and abundant moisture allow for the production of a wide variety of crops. These same climatic conditions have unique influences on nutrient management and externalities.

As mentioned previously, no single farm type or farm size dominates agricultural land use within the valley. Average farm size is small relative to the U.S. and the Western states (table III-3). The northern portion of the valley, with its proximity to the Portland metropolitan area, has generally smaller farms than the southern valley, and much of the land in the north contains hobby farms and small pastures [OSU Extension Service 1988].

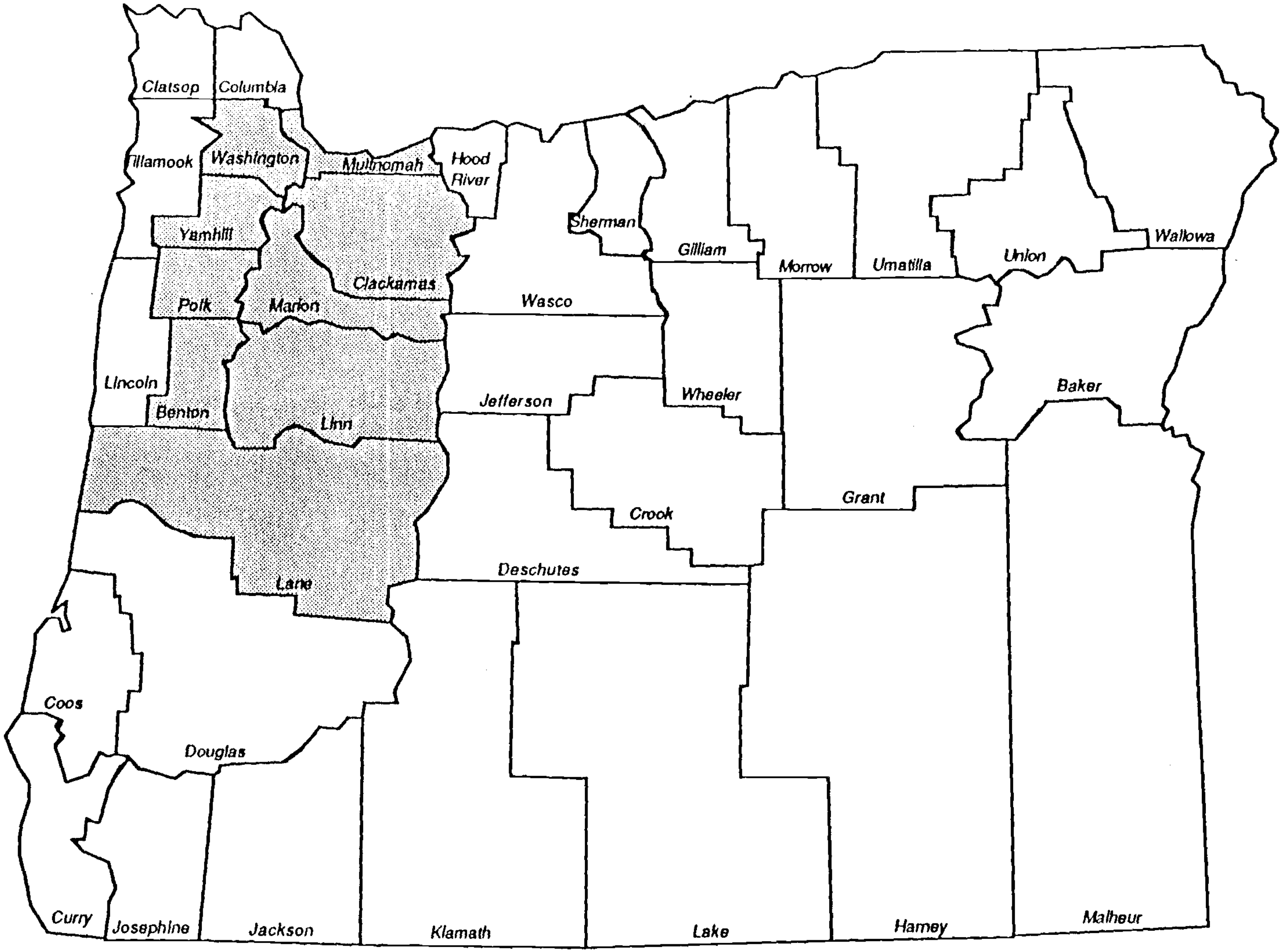
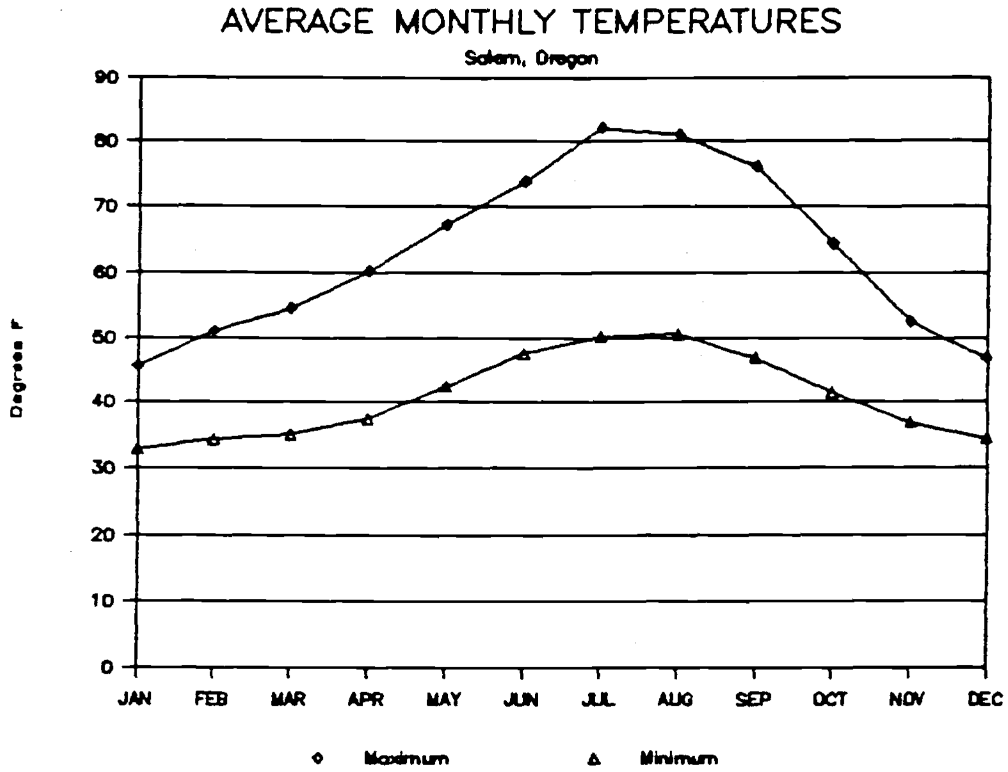



Figure III-2. Location of study. Shaded counties are those included in the analysis.



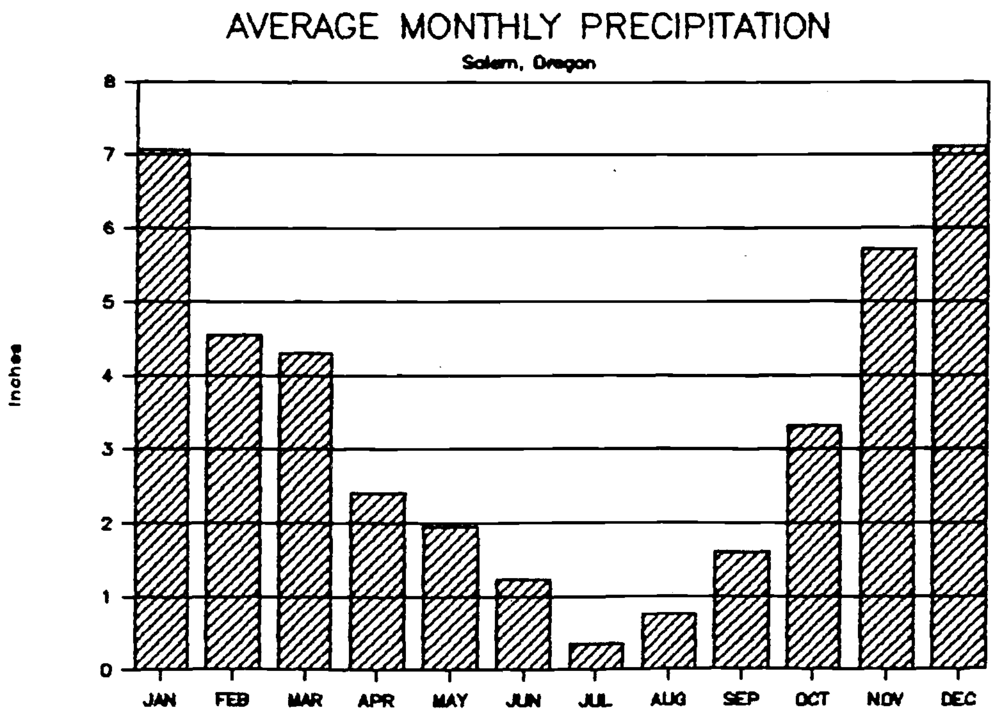




Figure III-3. Temperature and precipitation averages for Salem, Oregon.

Table III-3. Land in farms and average farm size, Willamette Valley, Oregon.

| | Land in farms (000 acres) | Average Farm size (acres) |
|---|---|---|
| NORTH VALLEY | | |
| Multnomah | 35.2 | 58 |
| Washington | 151.1 | 79 |
| Clackamas | 176.4 | 51 |
| CENTRAL VALLEY | | |
| Yamhill | 196.2 | 109 |
| Marion | 311.0 | 110 |
| Polk | 179.5 | 150 |
| SOUTH VALLEY | | |
| Benton | 123.3 | 171 |
| Linn | 374.5 | 182 |
| Lane | 272.2 | 123 |
| TOTAL | 1819.4 | 108 |

Source: U.S. Department of Agriculture, Census of Agriculture, 1982.

Marion County, in the central part of the valley, contains the most diverse and intensively managed farms of the area. Vegetables for processing, orchards, berries, wheat, grass seed, and dairy products are the prominent products. Marion County also has the largest gross farm sales of any county in the state [Miles].

The southern valley (Linn, Benton and Lane counties) contain the largest farms (though still averaging less than 200 acres), with generally the poorest soils. Most soils are poorly drained; such soils are well-suited to the growing of grass for seed. Limited acreage of other crops including vegetables (fresh and for processing), wheat, and hay are grown where soil is tiled for improved drainage.

The foothills are generally not farmed intensively; much of the land remains in woodlots, pastures and Christmas tree farms. Exceptions are the hills of Marion, Polk and Clackamas counties, where considerable acreages of grass for seed and wheat are raised. Some foothill areas also produce wine grapes, orchards, berries, and vegetables.

*D.2 Agricultural externalities.*

There have been few studies of agricultural externalities in the Willamette Valley. However, those studies that have been conducted show "frequent contamination" of surface and ground water [Oregon Department of Environmental Quality, p. 24]. Soil erosion is not considered a general problem, despite the high annual rainfall, but is a localized problem under special circumstances [N. Christensen]. A few cultivated foothill areas, however, are subject to moderate to severe erosion.

Nitrate and nutrients in surface water has been identified as potentially serious. The U.S.D.A. [1987] found nitrate nitrogen ($NO_3N$) levels of at least 3 ppm in wells in Linn and parts of Marion counties, and identified Linn county as having the potential for groundwater contamination from nitrogen fertilizers.

The Oregon Department of Environmental Quality (ODEQ) has identified sources of groundwater pollution in the Willamette Valley near Jefferson and north of Salem along the Willamette River (Mission Bottoms), with agriculture identified as the source of such pollution [Oregon Department of Environmental Quality, p. 23].

The ODEQ also identified waterways in the state which are "areas of environmental concern." All rivers in the Willamette Basin were classified as having moderate or severe impairment problems (occasional or frequent interference with water-based activities, respectively) due to nonpoint source pollution (table III-4).

Table III-4. Surface water pollution from nonpoint sources in the Willamette River Basin. (Adapted from ODEQ, p. 35-41.)

| River | Not meeting standards* Agri. | Not meeting standards* Forestry | NPS severe impairment | NPS moderate impairment |
|---|---|---|---|---|
| Tualatin | x | x | x | |
| N. Yamhill | x | x | x | |
| S. Yamhill | x | x | | x |
| Luckiamute | x | x | x | |
| Mary's | | x | | x |
| Long Tom | | | x | |
| Mohawk | | | | x |
| Calapooia | | | | x |
| S. Santiam | x | x | | x |
| N. Santiam | | | | x |
| Pudding | x | | x | |
| Willamette | | | | |
| i. upper | | | | x |
| ii. middle | | | | x |
| iii. lower | x | x | | x |

* Rivers which do not meet standards set to protect water quality for fishing and swimming, due to animal waste, soil erosion and fertilizer runoff arising from agricultural and forestry practices.

The nature of the winter climate and amount of cultivated land under fall seeding creates the potential for significant nitrogen leaching in the Willamette Valley. It is acknowledged that, in general, Willamette Valley farmers apply more fertilizer to crops than is economically or agronomically necessary for proper and sustained growth, as a result of leaching and the high marginal value of nitrogen fertilizer [Karow].

*D.3 Soils*

The nature of the soil resource on a farm not only influences crop productivity and selection, but plays an important role in the level and amounts of nutrient runoff and leaching. Several hundred soil types are found in the counties of the Willamette Valley; however, a relative handful dominate the total acreage. Those of importance to this analysis are identified here (table III-5).

The three topographic classifications of production in the valley include: the (1) river bottom and floodplains, (2) upland terraces, and (3) foothills. Each of these classifications has somewhat unique soil characteristics. These represented in the analysis are outlined below.

Bottomlands. The bottomlands include the floodplains of the Willamette Valley and its tributaries. They represent important vegetable growing regions, particularly in the central part of the valley. Soils in the river bottoms are generally deep, nearly level, and range from very well drained to very poorly drained.

The Chehalis soil is very well drained with superior water-holding qualities and, together with the similar

Table III-5. Acreages of represented soil classes of the Willamette Valley.

| | Soil Class | EPIC Soil | Lane | Benton | Linn | Polk | Marion | Yamhill | Wash. | Clack. | Mult. | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (A) | BOTTOMLANDS: | | | | | | | | | | | |
| | Chehalis | Chehalis | 9,300 | 10,365 | 10,895 | 4,672 | 5,730 | 5,710 | 7,901 | 2,274 | | 56,847 |
| | Cloquato | Chehalis | 5,170 | 4,806 | 8,350 | 3,063 | 20,165 | 5,410 | | 5,373 | | 52,337 |
| 1. | SUBTOTAL | | 14,470 | 15,171 | 19,245 | 7,735 | 25,895 | 11,120 | 7,901 | 7,647 | 0 | 109,184 |
| | Wapato | Wapato | 2,320 | 1,217 | 4,920 | 3,053 | 11,008 | 9,670 | 11,548 | 5,381 | 1,136 | 50,253 |
| 2. | SUBTOTAL | | 2,320 | 1,217 | 4,920 | 3,053 | 11,008 | 9,670 | 11,548 | 5,381 | 1,136 | 50,253 |
| | TOTAL: BOTTOMLANDS | | 16,790 | 16,388 | 24,165 | 10,788 | 36,903 | 20,790 | 19,449 | 13,028 | 1,136 | 159,437 |
| (B) | TERRACES: | | | | | | | | | | | |
| | Coburg | Woodburn, 3% | 13,480 | 7,233 | 16,165 | 3,465 | | | | 3,729 | | 44,072 |
| | Malabon | Woodburn, 3% | 15,350 | 8,265 | 13,445 | 4,810 | | | | 405 | | 42,275 |
| | Woodburn, 0-3% | Woodburn, 3% | 215 | 8,339 | 30,490 | 13,844 | 61,230 | 15,955 | 20,300 | 3,122 | | 153,495 |
| | Willamette, 0-3% | Woodburn, 3% | | 2,428 | 7,125 | 2,092 | 9,730 | 4,660 | 5,155 | 2,878 | | 34,068 |
| 1. | SUBTOTAL | | 29,045 | 26,265 | 67,225 | 24,211 | 70,960 | 20,615 | 25,455 | 10,134 | 0 | 273,910 |
| | Woodburn, 4-7% | Woodburn, 6% | | 905 | 520 | 4,116 | 4,789 | 15,955 | 10,877 | 13,278 | | 50,440 |
| | Willamette, 4-7% | Woodburn, 6% | | 2,299 | | 1,039 | 635 | 435 | 1,666 | 1,924 | | 7,998 |
| 2. | SUBTOTAL | | 0 | 3,204 | 520 | 5,155 | 5,424 | 16,390 | 12,543 | 15,202 | 0 | 58,438 |
| | Woodburn, 8-11% | Woodburn, 10% | | 904 | 520 | 4,116 | 4,788 | 2,700 | 2,124 | 3,465 | | 18,617 |
| | Willamette, 8-11% | Woodburn, 10% | | 2,298 | | 1,039 | 635 | 435 | 293 | 192 | | 4,892 |
| 3. | SUBTOTAL | | 0 | 3,202 | 520 | 5,155 | 5,423 | 3,135 | 2,417 | 3,657 | 0 | 23,509 |
| | Woodburn, 12-20% | Woodburn, 15% | | | | 945 | 4,490 | 2,200 | 726 | 2,080 | | 10,441 |
| | Willamette,12-20% | Woodburn, 15% | | | | 204 | | 380 | 211 | 118 | | 913 |
| 4. | SUBTOTAL | | 0 | 0 | 0 | 1,149 | 4,490 | 2,580 | 937 | 2,198 | 0 | 11,354 |
| | ALL WOODBURN & WILLAMETTE | | 29,045 | 32,671 | 68,265 | 35,670 | 86,297 | 42,720 | 41,352 | 31,191 | 0 | 367,211 |
| | Amity | Amity | | 6,100 | 26,700 | 9,721 | 45,109 | 13,360 | 6,092 | 5,943 | | 113,025 |
| | Dayton | Dayton | 4,280 | 15,362 | 59,075 | 9,767 | 10,440 | 4,420 | 2,672 | 5,772 | | 111,788 |
| | Concord | Dayton | | 1,198 | 10,835 | 5,755 | 14,980 | | | 2,293 | | 35,061 |
| 5. | SUBTOTAL | | 4,280 | 22,660 | 96,610 | 25,243 | 70,529 | 17,780 | 8,764 | 14,008 | 0 | 259,874 |
| | TOTAL: TERRACES | | 33,325 | 55,331 | 164,875 | 60,913 | 156,826 | 60,500 | 50,116 | 45,199 | 0 | 627,085 |
| (C) | FOOTHILLS: | | | | | | | | | | | |
| | Jory, 2-7% | Jory, 5% | 2,280 | 1,426 | 4,708 | 3,220 | 8,698 | 3,305 | 411 | 28,201 | | 52,249 |
| | Nekia, 2-7% | Jory, 5% | 2,430 | | 5,555 | 2,585 | 20,743 | 560 | | 1,504 | | 33,377 |
| | Bellpine, 3-7% | Jory, 5% | 7,925 | 842 | 3,368 | 5,193 | | | | | | 17,328 |
| 1. | SUBTOTAL | | 12,635 | 2,268 | 13,631 | 10,998 | 29,441 | 3,865 | 411 | 29,705 | 0 | 102,954 |
| | Jory, 8-12% | Jory, 10% | 3,051 | 2,155 | 5,377 | 3,770 | 9,110 | 4,185 | 474 | 13,459 | | 41,581 |
| | Nekia, 8-12% | Jory, 10% | 4,154 | | 6,648 | 2,977 | 22,259 | 1,727 | | 1,986 | | 39,751 |
| | Bellpine, 8-12% | Jory, 10% | 14,436 | 1,246 | 4,381 | 6,361 | | | | | | 26,424 |
| 2. | SUBTOTAL | | 21,641 | 3,401 | 16,406 | 13,108 | 31,369 | 5,912 | 474 | 15,445 | 0 | 107,756 |
| | Jory, 13-20% | Jory, 15% | 6,169 | 5,832 | 5,356 | 4,401 | 3,297 | 7,040 | 500 | 7,511 | | 40,106 |
| | Nekia, 13-20% | Jory, 15% | 13,796 | | 8,747 | 3,140 | 12,132 | 2,303 | | 1,128 | | 41,246 |
| | Bellpine, 13-20% | Jory, 15% | 52,089 | 3,228 | 8,107 | 9,347 | | | | | | 72,771 |
| 3. | SUBTOTAL | | 72,054 | 9,060 | 22,210 | 16,888 | 15,429 | 9,343 | 500 | 8,639 | 0 | 154,123 |
| | TOTAL: FOOTHILLS | | 106,330 | 14,729 | 52,247 | 40,994 | 76,239 | 19,120 | 1,385 | 53,789 | 0 | 364,833 |
| | TOTAL: FOOTHILL CROPLAND | | 35,340 | 5,327 | 23,549 | 18,730 | 42,322 | 7,917 | 666 | 33,215 | 0 | 167,064 |
| | TOTAL: ALL SOILS | | 156,445 | 86,448 | 241,287 | 112,695 | 269,968 | 100,410 | 70,950 | 112,016 | 1,136 | 953,586 |

Cloquato, represents 109,000 acres. It is the most intensively farmed of all soils, supporting all cultivated and orchard crops adapted to the area. A cover crop is considered necessary to protect the surface from periodic flooding in winter.

Wapato soils amount to about 50,000 acres; this soil is very poorly drained, remaining wet through late spring. It is adaptable only to hay, pasture, and grass seed production, although with drainage other crops are possible.

Terraces. The majority of crop acreage in the valley is situated on broad stretches of terrace or bench land. These contain farms of great diversity, including grass seeds, vegetables, grains, pasture, orchards and berries. Soils range from the fertile and well-drained to the heavy and poorly drained "whiteland" clays.

The north and central valley contain large areas of Woodburn, Willamette, Coburg, and Malabon soils. These are deep, well-drained soils capable of growing all valley crops. Together, these soils amount to approximately 367,000 acres. Most of the terrace soils are contained on slopes of less than one percent. However, some 93,000 acres of these soils are sloped to as much as twenty percent, though most are less than ten percent. This has some influence on the ability of the land to support row crop production.

Two other soil types of the central and southern valley that are often found in close association are Amity and Dayton. They are both poorly drained and heavy, supporting limited cropping options. Amity is somewhat lighter than Dayton and, if drainage is installed, is capable of producing vegetables and berries. However, the expense of installing drainage is generally not justified in the southern valley because the aligned Dayton soils are helped little by drainage [Huddleston].

Amity soils are found on 113,000 acres, and Dayton (along with the similar Concord) are found on 147,000 acres. The large stretches of these soils, particularly in Linn County, are used primarily for grass seed production under relatively large farm sizes (two to five thousand acres each).

Foothills. The foothills along the border of the valley contain the largest acreage of the valley counties, but a relatively small portion of it is in agricultural use. That which is used for agriculture tends to be in pastures of widely varying sizes (small, 5-acre homesteads near the Portland metropolitan area, to large commercial ranches of many hundreds of acres) [OSU Extension Service 1987; 1988]. In addition, many thousands of acres of foothill soils are cultivated to the full range of Willamette Valley crops.

A considerable portion of the foothills contain Jory, Nekia, and Bellpine soils. These are all well-drained, though Nekia and Bellpine are somewhat shallow (usually less than one meter). Slopes vary from two percent to over thirty percent, with most in the five to fifteen percent range. As most of this land is not under annual cultivation, erosion is generally not a problem. However, these soils, particularly of the steeper slopes, are subject to severe erosion.

The Jory soil type (up to 30 percent slope) is found on 153,000 acres, and Nekia and Bellpine together amount to 195,000 acres. It is not generally known what portion are in agricultural uses.

The fate of fertilizers on these soils is particularly important. Being well-drained and, in the case of Nekia and Bellpine, shallow to bedrock, conditions appear suitable for groundwater contamination. However, it is not clear whether percolate enters the groundwater through fissures and cracks, or follows the land slope to emerge as surface runoff [Huddleston].

*D.4 Crops.*

The nine counties of the Willamette Valley contain over 1.8 million acres of land in farms, with 1.246 million in cropland, 315,000 in woodland, and 475,000 in pasture. Some 964,000 acres of harvested cropland were reported in 1982 [U.S. Department of Commerce 1984] (table III-6).

No single crop or commodity dominates the acreage in the Willamette Valley, as no single farm can be considered "representative" (figure III-4). Therefore, the crops and

Table III-6. Crop acreages, by county, in the Willamette Valley (000 acres) (1982).

| | Lane | Linn | Benton | Polk | Marion | Yamhill | Clack | Wash | Mult | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| Harvested cropland | 91.9 | 227.5 | 65.9 | 104.5 | 197.0 | 105.8 | 68.1 | 87.6 | 15.7 | 964.0 |
| Wheat for grain | 12.4 | 26.8 | 13.4 | 39.0 | 41.8 | 39.9 | 9.7 | 25.2 | 3.1 | 211.3 |
| Oats for grain | 2.3 | 3.5 | 1.9 | 10.0 | 6.3 | 10.0 | 4.9 | 11.9 | 0.2 | 51.0 |
| Vegetables | 8.6 | 8.4 | 6.6 | 3.8 | 41.2 | 8.4 | 5.9 | 4.5 | 2.4 | 89.8 |
| Snap beans | 2.8 | 2.3 | 1.8 | 0.5 | 13.8 | 2.1 | 0.5 | 0.9 | | 24.7 |
| Green peas | | 0.2 | 0.5 | | 2.9 | | 0.5 | | | 4.1 |
| Sweet corn | 4.0 | 4.7 | 3.8 | 2.9 | 18.4 | 4.7 | 2.2 | 1.6 | | 42.3 |
| Land in orchards | 4.3 | 1.4 | 0.8 | 6.4 | 8.0 | 10.6 | 4.1 | 9.5 | 0.2 | 45.3 |
| Filberts, Hazle. | 2.5 | 0.8 | 0.4 | 1.6 | 4.7 | 5.1 | 3.4 | 5.5 | | 24.0 |
| Ryegrass seed | 16.7 | 128.5 | 18.6 | 11.7 | 13.7 | 2.0 | 0.8 | 0.0 | 0.0 | 192.0 |
| Fescue seed | 4.5 | 10.3 | 3.8 | 2.9 | 24.4 | | 2.0 | | | 47.9 |
| Kentucky Bluegrass | 0.5 | 5.0 | | | 3.0 | | 0.5 | | | 9.0 |
| Hay - All | 32.2 | 22.3 | 8.1 | 12.9 | 19.7 | 19.8 | 27.2 | 18.3 | 4.0 | 164.5 |
| Tame hay | 24.7 | 16.3 | 5.6 | 8.5 | 10.5 | 12.2 | 19.9 | 8.8 | 8.5 | 115.0 |
| Mint for oil | 4.8 | 3.5 | 1.9 | 0.9 | 6.2 | | | | | 17.3 |

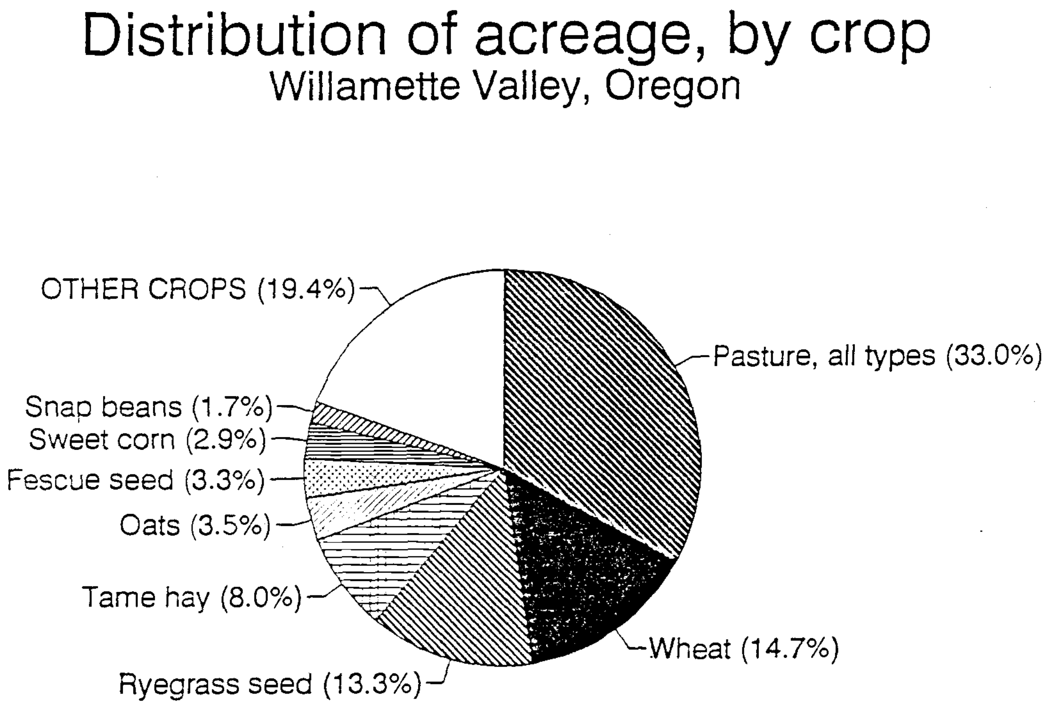



Figure III-4. Distribution of acreage, by crop.

land uses chosen for the simulation analyses are selected on the basis of (1) total acres in the crop, (2) unique features which can represent similar crops, and (3) economic importance. They are presented below, in descending order by total acreage.

Pasture. Land in pasture occurs on all soil types, and represents commercial pastures for cattle and calves, dairy farms, small farms and homesteads, and hobby farms. Both rainfed and irrigated pasture is considered. Not all pastureland is improved, but the represented enterprise in this analysis is a seven-year, 50-acre field fertilized spring and fall [OSU Extension Service 1975a, 1975c, 1976a].

Winter wheat. More than 200,000 acres of winter wheat were harvested in the valley in 1988 [Miles], with nearly sixty percent in Polk, Marion, and Yamhill counties. Wheat is grown on well-drained soils, and is either monocropped or grown in rotation with oats or oats followed by clover [Karow]. It is also grown following perennial grass seed in the foothills.

Most of the crop is tilled and planted under a conventional (mold-board plow) system, but no-till and reduced tillage managements are used. The representative enterprise is a one-hundred acre field of a five-hundred acre farm [Taylor, et al. 1989a].

<u>Tame hay</u>. Hay crops accounted for 218,000 acres in 1988, with about two-thirds of that in the form of "tame hay." This is usually a mixed-seeded grass (not alfalfa) that may be cut and dried or pastured, or may be in rotation with grains and/or row crops. It may also be irrigated depending upon proximity to water.

<u>Annual and perennial ryegrass seed</u>. The Willamette Valley is a premier cool season grass seed growing region, producing and supplying nearly 75 percent of the nation's total grass seed [Ryan, et al.] (table III-7). Annual and perennial ryegrass account for the greatest acreage, about 47 percent of the valley's acreage in grass seed [Miles]. Annual ryegrass is used in the Southeastern United States as an overwintering cover crop and for lawns, and perennial ryegrass is used in pastures and lawns.

Table III-7. Distribution of grass seed production in the Willamette Valley, 1988 (preliminary).

| | Harvested Acres | | | |
|---|---|---|---|---|
| | North | Central | South | TOTAL |
| Bentgrass, Colonial | -- | 4,200 | 2,700 | 6,900 |
| Bentgrass, Creeping | 350 | 2,200 | 1,150 | 3,700 |
| Bluegrass, Kentucky | 750 | 2,950 | 3,480 | 7,180 |
| Fescue, Chewings | 3,500 | 9,580 | 1,350 | 14,430 |
| Fescue, Tall | 1,000 | 26,600 | 41,050 | 68,650 |
| Fescue, Red | 2,580 | 5,550 | 1,250 | 9,380 |
| Ryegrass, Annual | 450 | 15,100 | 91,900 | 107,450 |
| Ryegrass, Perennial | 1,600 | 29,900 | 57,800 | 89,300 |
| Orchardgrass | 820 | 10,200 | 14,600 | 25,620 |

Source: Oregon State University Extension Service, unpublished data, 1989.

The market for perennial ryegrass is driven by supply of grass seeds from the Willamette Valley [Ryan, et al.; Conklin]. Much of it is proprietary (or privately-owned varieties), which are grown on contract with distributors. Contracts have traditionally been five to eight years, but have tended to shorten to three or four in recent years [Conklin; Young]. The causes for this shorter rotation are mainly institutional[4] and market-driven, and not for agronomic reasons since perennial grass seeds may be grown for ten to fifteen years from a single seeding without a significant loss in yield [Young].

Annual ryegrass seed is often considered the grass seed crop "of last resort" [Ryan, et al., p. 52; Young]; it is generally of lower quality than other seeds, and does not command as high a price. Nevertheless, it is very well adapted to growing conditions unsuitable for other uses. Annual ryegrass may be grown in heavy, poorly drained and even flood-prone soils. It is also occasionally grown in rotation alternating with wheat [Taylor, et al. 1989b]. As with perennial ryegrass, annual ryegrass fields are often burned after each season. They are planted under both conventional and no-till management systems [Youngberg, et al., 1985a].

---

[4] The institutional forces affecting the grass seed industry are political constraints imposed on the practice of field-burning, used extensively for sanitation of the seed product and, often, as an inexpensive means of removing straw. More information on the field-burning issue are in Conklin, et al.

Tall fescue seed. The only other grass seed crop represented in the simulations is tall fescue. It was grown on about 78,000 acres in 1987 [U.S. Department of Commerce 1989]. The product is used extensively as a cover crop and for pastures; however, new genetic improvements of the seed are being developed which rival the quality of other seeds used in lawns. This led to a large increase in the acreage devoted to fescue production. Another factor affecting its supply is its resistance to fungal disease, allowing farmers to reduce or forego field-burning [Conklin; Young].

Tall fescue is nearly all proprietary, and is grown on contracts of three to five years [Conklin]. The first year's production is only two-thirds to three-fourths of a full production yield [Youngberg, et al. 1985b].

Spring oats. Production of oats was 51,000 acres in 1982 [U.S. Department of Commerce 1984], but has declined considerably since that time [Karow] due to an increase in the price of wheat. Oats are grown primarily in the foothills in rotation with wheat or wheat and clover. Much of the oat acreage is seeded in the spring [OSU Extension Service 1975b; 1976b].

Sweet corn for processing. Nearly 90,000 acres are devoted to vegetable production, and 38,500 of that is in sweet corn for processing. Most of this is in Marion

County.

Vegetables are grown generally in well-drained soils under irrigation. Land slopes are limited to about 5% for effective harvesting [Soil Conservation Service]. As a late spring seeded crop, winter cover crops are recommended to farmers for protection of the soil resource [Cross, et al. 1988a].

Snap beans for processing. About 21,000 acres are devoted to snap bean production. Though generally quite profitable, production is limited by availability of contracts with food processors and the high capital investment and other production costs [Cross, et al. 1988b]. Snap beans are usually grown in rotation with sweet corn, and occasionally with corn and wheat.

Christmas trees. Although the harvested acreage of Christmas trees is minor relative to cultivated crops (just 4,500 harvested acres[5] in 1988 [Miles]), Christmas trees produce high returns and are usually a very profitable use of foothill land [OSU Extension Service 1977]. While trees are well-adapted to foothill soils and climate, production methods can often result in severe erosion unless measures are taken to control runoff.

---

5 Total acreage of land in Christmas trees is 6 or more times the quantity harvested, or at least 27,000 acres.

**E. Data sources.**

Crop budgets for winter wheat and annual ryegrass seed were developed from interviews with area farmers and Crop Extension Agents during the summer of 1989. These budgets were designed to be representative for the region and reflect input-output levels and costs. They include information on equipment, tillage, management, timing, fertilizer applications, and other inputs. Crop budgets published by the Oregon State University Extension Service were used for the remainder of the crops, and were updated to current (1989) costs and prices.

The EPIC soil data bases were used for modeling Woodburn, Dayton, and Jory soils. Information about Wapato, Chehalis, Amity, and Nekia soils were obtained from Herb Huddleston, Extension Soil Scientist, and from published soil surveys.

Prices and yield information were gathered from commodity data sheets published by the Extension Service. Finally, information on crops, crop rotations, and management were obtained through interviews and discussions with Extension and Soil Conservation Service personnel.

**F. Environmental policy regulations.**

The spatial variability and stochastic characteristics of nonpoint pollution can invalidate or render difficult the control policies available for point-source emissions, as discussed in Chapter II. Shortle and Dunn addressed this problem and examined the relative efficiency of four general strategies that have been suggested for achieving agricultural nonpoint pollution abatement. These four, and one more, are used in this analysis and are outlined below.

*F.1 Economic incentives I: an effluent tax.*

A Pigouvian tax can be applied to estimated soil loss to account for the social cost of the soil erosion externality. However, the fate of nitrogen is of primary concern in the Willamette Valley. Therefore, a per-unit tax of various levels on leachate of nitrogen is used in this study. This is implemented in the formulation by placing into the objective function a "price" equivalent to the tax on $NO_3$ lost from the root zone:

$$\text{Max} \quad PRICE_i X_i - EXPEND_s C_s - LAND_k Z_k - TAX_{NO3} Q_{NO3}$$

Appropriate tax levels should reflect the marginal damage caused by a unit of effluent, or the cost of removing it from the water. No effort has been made in this study to estimate damage functions, and few studies of the cost of removal are available. However, Walker and Hoehn estimated the annual damages due to nitrate contamination of a rural water supply (groundwater source). They calculated the cost of removing nitrates to be $11.98 per pound[6]. Pigouvian tax levels of $1, $2, $4, $6, $8, and $12 were used in this

[6] Walker and Hoehn estimated the cost of reducing nitrates from 15 mg/l to 5 mg/l to be $1.00 per thousand gallons. This amounts to $26.42/kg, or $11.98/lb.

study for leached nitrates, surface runoff of organic nitrogen and nitrates, and both classes combined, where appropriate.

*F.2 Economic incentives II: an input tax.*

A tax on the nutrient (nitrogen) which closely affects the externality is an attempt at forcing more effective utilization of inputs by causing the marginal social cost of the externality to be reflected in the cost of the input. This is implemented by adding the tax of 50% and 100% to the cost of nitrogen in the objective function:

$$EXPEND_{nitrogen}^{*} = EXPEND_{nitrogen} + TAX_{nitrogen}$$

*F.3 Estimated effluent standards.*

This policy places a maximum limit on per-acre runoff (or leachate). The effect of the constraint is to either eliminate certain rotations (highly erosive, or which result in excessive leaching or runoff) from consideration, or cause other combinations of inputs to be used (for example, lower nitrogen usage on corn). The policy is implemented by imposing an additional constraint:

$$ENV_{fk} \leq LIMIT_{f}$$

While standards do limit production options available to the farmer, no additional cost (i.e., tax) is incurred.

*F.4 Management standards: Required use of a particular BMP.*

A requirement that only particular cultural practices be allowed has the effect of limiting the choice options available to farmers. The implementation here is to eliminate those unacceptable practices from the set of alternatives. In many farm regions in the country a required use of no-till drills has been suggested. This policy is examined here, applied to small grains and grass seed production.

*F.5 Control: Fall fertilizer ban.*

A fifth policy of particular applicability to Pacific Northwest conditions is to ban the use of nitrogen fertilizer in certain months for which crop utilization is likely to be low and the potential for leaching is high. Since leaching is greatest in the late fall and winter months, a ban on fertilizer use in autumn months is a logical option. This is implemented by eliminating from the production set those rotation sets which include fall nitrogen fertilization. Note that the full production set does include fall sown crops (such as wheat and grass seed) with only winter fertilizer applications.

# IV. RESULTS AND IMPLICATIONS OF POLLUTION CONTROL OPTIONS

The major objective of this research is to assess the economic effects of changes in farm-level behavior in response to measures aimed at controlling agricultural pollution. Chapter III presented the framework for such an assessment. The results and implications of applying that framework are presented in this chapter in five sections. The first section contains a summary of EPIC model results for the eleven soil-slope combinations defined on the five representative farms. These model outputs provide an indication of the feasible options and quantify the level of effluent from soil-crop rotations for alternatives found on farms in the Willamette Valley.

The second section reports on the current or "status quo" situation (unrestricted scenario) as computed by the linear programming model for each of the five farms. This represents both the farms' unregulated profit potential and an indication of the severity of effluent problems, as well as the focus for pollution control.

In the third section, results from applying various pollution control mechanisms are presented. Each farm's analysis contains both a set of "optimal" (least cost) solutions and an application of the control measures which affect production methods and pollution. A discussion of the applicability of these policies to each of the farms is included.

Section four addresses the effectiveness of policy measures for meeting economic and abatement goals across the five representative farms. Tradeoffs between effluent control and farm-level profit are central to designing cost-effective non-point pollution controls.

The final section contains implications of these results on farming practices and the prospects for agricultural pollution control. The discussion provides some insight for policy recommendations.

**A. Results of EPIC simulations.**

EPIC simulations provide detailed information on soil qualities, weather conditions, resource flow, and crop growth conditions. Only those data most relevant to this study are presented for discussion here. These include crop yield (adjusted by index), erosion rate, organic nitrogen (N) loss in sediment, nitrate ($NO_3$-N) loss in runoff, nitrates leached, and phosphorus (P) loss in runoff.

Table IV-1 contains the results for the well-drained bottomland vegetable farm, consisting entirely of Chehalis soils. Crop yields from this soil are among the highest in the valley, with very low erosion and surface nutrient losses. Simulated levels of leached nitrates, however, are quite high (more than 20 lbs. per acre) for fully fertilized vegetable crops and wheat. Considerable reductions in leachate can be achieved with lower nitrogen application

Table IV-1. Results of EPIC simulations for well-drained bottomland.

| Chehalis - 1% slope | | | | | Soil | --- Runoff --- | | Leached | Phos. |
|---|---|---|---|---|---|---|---|---|---|
| | | ----- CROP YIELDS ---- | | | Erosion | Org. N | $NO_3$-N | $NO_3$-N | Runoff |
| CROP ROTATION | MGMT | Crop 1 | Crop 2 | Crop 3 | (T) | (lb) | (lb) | (lb) | (lb) |
| Wheat | Conventional | 100 bu | | | 0.44 | 1.20 | 3.57 | 41.04 | 0.00 |
| Wheat | Reduced till | 100 bu | | | 0.43 | 1.20 | 3.57 | 40.15 | 0.00 |
| Wheat | No-till | 102 bu | | | 0.07 | 0.32 | 4.46 | 37.47 | 0.89 |
| Wheat | (No fall N) | 99 bu | | | 0.44 | 1.20 | 3.57 | 30.33 | 0.00 |
| Wheat/Grass seed | Con/Con | 110 bu | 1110 lbs | | 0.25 | 0.72 | 3.57 | 25.87 | 0.00 |
| Wheat/Aust. Peas | Con/Con | 97 bu | | | 0.30 | 0.91 | 2.68 | 65.13 | 0.00 |
| Annual ryegrass | Conventional | 1160 lbs | | | 0.03 | 0.14 | 1.78 | 11.60 | 0.00 |
| Annual ryegrass | No-till | 1210 lbs | | | 0.03 | 0.29 | 1.78 | 5.35 | 0.00 |
| Ryegrass (5)/Wheat | Con/Con | 1086 lbs | 104 bu | | 0.01 | 0.07 | 0.00 | 8.03 | 0.00 |
| Ryegrass (5) | Conventional | 1100 lbs | | | 0.01 | 0.05 | 0.00 | 2.68 | 0.00 |
| Ryegrass (5) | - 75% fert | 894 lbs | | | 0.01 | 0.04 | 0.00 | 1.78 | 0.00 |
| Ryegrass (5) | - 50% fert | 690 lbs | | | 0.01 | 0.04 | 0.00 | 1.78 | 0.00 |
| Ryegrass (5) | (No fall N) | 1038 lbs | | | 0.01 | 0.04 | 0.00 | 1.78 | 0.00 |
| Fescue (5)/Wheat | Con/Con | 1186 lbs | 104 bu | | 0.01 | 0.07 | 0.00 | 8.03 | 0.00 |
| Fescue (5) | Conventional | 1200 lbs | | | 0.01 | 0.05 | 0.00 | 2.68 | 0.00 |
| Fescue (5) | - 75% fert | 976 lbs | | | 0.01 | 0.04 | 0.00 | 1.78 | 0.00 |
| Fescue (5) | - 50% fert | 752 lbs | | | 0.01 | 0.04 | 0.00 | 1.78 | 0.00 |
| Fescue (5) | (No fall N) | 1132 lbs | | | 0.01 | 0.04 | 0.00 | 1.78 | 0.00 |
| Dryland pasture | | 12 AUM | | | 0.02 | 0.06 | 0.00 | 9.81 | 0.89 |
| Irrigated pasture | | 18 AUM | | | 0.00 | 0.02 | 0.00 | 6.25 | 0.00 |
| Dryland hay | | 2.1 T | | | 0.02 | 0.06 | 0.00 | 9.81 | 0.89 |
| Irrigated hay | | 3.2 T | | | 0.00 | 0.02 | 0.00 | 6.25 | 0.00 |
| Continuous corn | | 9.1 T | | | 0.53 | 1.28 | 2.68 | 35.69 | 0.89 |
| Continuous corn | - 75% fert | 8.7 T | | | 0.47 | 1.15 | 1.78 | 24.09 | 0.89 |
| Continuous corn | - 50% fert | 8.2 T | | | 0.42 | 1.02 | 1.78 | 12.49 | 0.89 |
| Corn/Beans | | 9.1 T | 5.9 T | | 0.59 | 1.37 | 1.78 | 23.20 | 0.89 |
| Corn/Beans | - 85% fert | 9.0 T | 5.5 T | | 0.58 | 1.33 | 1.78 | 18.74 | 0.89 |
| Corn/Beans | - 75% fert | 8.5 T | 5.0 T | | 0.58 | 1.30 | 1.78 | 16.06 | 0.89 |
| Corn/Beans | - 50% fert | 7.9 T | 4.0 T | | 0.56 | 1.23 | 1.78 | 8.92 | 0.89 |
| Corn/Beans/Wheat | Winter cover | 9.1 T | 6.0 T | 98 bu | 0.35 | 0.96 | 3.57 | 15.17 | 0.89 |
| Corn/Beans/Wheat | - 85% fert | 9.0 T | 5.7 T | 87 bu | 0.35 | 0.95 | 2.68 | 12.49 | 0.89 |
| Corn/Beans/Wheat | - 75% fert | 8.8 T | 5.3 T | 81 bu | 0.35 | 0.96 | 2.68 | 0.00 | 0.00 |
| Corn/Beans/Wheat | - 50% fert | 8.5 T | 4.7 T | 64 bu | 0.35 | 0.96 | 2.68 | 0.00 | 0.00 |
| Corn/Clover | | 9.0 T | | | 0.27 | 0.94 | 2.68 | 21.41 | 0.89 |
| Corn/Clover | - 75% fert | 8.6 T | | | 0.27 | 0.89 | 1.78 | 16.06 | 0.89 |
| Corn/Clover | - 50% fert | 8.1 T | | | 0.26 | 0.84 | 1.78 | 11.60 | 0.89 |
| Corn/Aust. Peas | | 8.6 T | | | 0.29 | 0.95 | 2.68 | 29.44 | 0.89 |

rates, and when winter cover crops are used. Leachate simulated under a continuous corn rotation is curtailed by more than fifty percent when shifting to a corn-bean-wheat rotation, using clover as a cover crop and partial source of nitrogen. Leachate under grass seed production is generally low -- less than 10 pounds per acre.

A different outcome applies to the poorly drained bottomland farm of Wapato soil (table IV-2). Far fewer cropping options exist and, with the exception of wheat in rotation, leaching of nitrates is not as much of a problem. Annual grass seed production (and wheat) results in nitrate losses in surface runoff of more than 10 pounds per acre. However, perennial grasses and pastureland are apparently somewhat more efficient in their utilization of applied nitrogen, though losing 5 to 9 pounds per acre to leaching.

The well-drained terrace farm is represented entirely by Woodburn soils, but with four different slopes. Steeper slopes limit cropping options, but also significantly affect effluent problems (table IV-3). Soil erosion increases considerably with steepness and surface-based nitrogen losses rise proportionally. This is especially true for the intensively-tilled small grains. Better erosion control is possible with perennial grasses or pasture. Nitrate leachate is a problem for vegetable crops not in rotation or using winter cover crops. Four to eight pounds per acre is leached from small grain rotations on all slopes.

Poorly-drained and somewhat poorly-drained terrace

Table IV-2. Results of EPIC simulations for poorly-drained bottomland.

------

| Wapato - 1% slope | | ----- CROP YIELDS ---- | | | Soil | --- Runoff --- | | Leached | Phos. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Erosion | Org. N | $NO_3$-N | $NO_3$-N | Runoff |
| CROP ROTATION | MGMT | Crop 1 | Crop 2 | Crop 3 | (T) | (lb) | (lb) | (lb) | (lb) |
| Wheat | Conventional | 50 bu | | | 1.20 | 4.39 | 16.06 | 24.09 | 0.89 |
| Wheat | Reduced till | 50 bu | | | 1.18 | 4.34 | 16.06 | 24.09 | 0.89 |
| Wheat | No-till | 50 bu | | | 0.16 | 0.84 | 18.74 | 23.20 | 1.78 |
| Wheat/Grass seed | Con/Con | 1680 lbs | 60 bu | | 0.64 | 2.54 | 16.06 | 12.49 | 0.89 |
| Wheat/Grass seed | Con/No-till | 1670 lbs | 61 bu | | 0.58 | 2.30 | 14.27 | 11.60 | 0.89 |
| Annual ryegrass | Conventional | 1800 lbs | | | 0.09 | 0.47 | 12.49 | 2.68 | 0.00 |
| Annual ryegrass | No-till | 1780 lbs | | | 0.09 | 0.64 | 14.27 | 1.78 | 0.89 |
| Annual ryegrass(NT) | - 75% fert | 1100 lbs | | | 0.09 | 0.56 | 10.71 | 0.89 | 0.00 |
| Annual ryegrass(NT) | - 50% fert | 1090 lbs | | | 0.09 | 0.48 | 7.14 | 0.89 | 0.00 |
| Annual ryegrass(NT) | (No fall N) | 1650 lbs | | | 0.09 | 0.46 | 12.49 | 0.89 | 0.00 |
| Ryegrass (5)/Wheat | Con/Con | 968 lbs | 50 bu | | 0.05 | 0.38 | 1.78 | 8.92 | 0.89 |
| Ryegrass (5) | Conventional | 976 lbs | | | 0.03 | 0.29 | 1.78 | 5.35 | 0.89 |
| Ryegrass (5) | - 75% fert | 804 lbs | | | 0.03 | 0.25 | 1.78 | 3.57 | 0.00 |
| Ryegrass (5) | - 50% fert | 606 lbs | | | 0.03 | 0.22 | 1.78 | 2.68 | 0.00 |
| Ryegrass (5) | (No fall N) | 919 lbs | | | 0.03 | 0.27 | 1.78 | 2.68 | 0.00 |
| Fescue (5)/Wheat | Con/Con | 1056 lbs | 50 bu | | 0.05 | 0.38 | 1.78 | 8.92 | 0.89 |
| Fescue (5) | Conventional | 1062 lbs | | | 0.03 | 0.29 | 1.78 | 5.35 | 0.89 |
| Fescue (5) | - 75% fert | 854 lbs | | | 0.03 | 0.25 | 1.78 | 3.57 | 0.00 |
| Fescue (5) | - 50% fert | 644 lbs | | | 0.03 | 0.22 | 1.78 | 2.68 | 0.00 |
| Fescue (5) | (No fall N) | 1000 lbs | | | 0.03 | 0.27 | 1.78 | 2.68 | 0.00 |
| Dryland pasture | | 8 AUM | | | 0.04 | 0.27 | 1.78 | 8.92 | 2.68 |
| Irrigated pasture | | 15 AUM | | | 0.04 | 0.25 | 0.89 | 7.14 | 2.68 |
| Dryland hay | | 1.4 T | | | 0.04 | 0.27 | 1.78 | 8.92 | 2.68 |
| Irrigated hay | | 2.7 T | | | 0.04 | 0.25 | 0.89 | 7.14 | 2.68 |

Table IV-3. Results of EPIC simulations for well-drained terraces.

Woodburn - 1% slope

| CROP ROTATION | MGMT | CROP YIELDS Crop 1 | Crop 2 | Crop 3 | Soil Erosion (T) | Runoff Org. N (lb) | Runoff $NO_3$-N (lb) | Leached $NO_3$-N (lb) | Phos. Runoff (lb) |
|---|---|---|---|---|---|---|---|---|---|
| Wheat | Conventional | 100 bu | | | 0.81 | 2.48 | 8.92 | 8.92 | 0.89 |
| Wheat | Reduced till | 100 bu | | | 0.79 | 2.52 | 8.92 | 8.92 | 0.89 |
| Wheat | No-till | 99 bu | | | 0.11 | 0.49 | 10.71 | 8.03 | 0.89 |
| Wheat | (No fall N) | 95 bu | | | 0.81 | 2.46 | 8.03 | 6.25 | 0.00 |
| Wheat/Grass seed | Con/Con | 121 bu | 1580 lbs | | 0.43 | 1.45 | 8.92 | 4.46 | 0.00 |
| Wheat/Grass seed | Con/No-till | 122 bu | 1580 lbs | | 0.39 | 1.34 | 8.03 | 4.46 | 0.89 |
| Wheat/Oats | Con/Con | 92 bu | 114 bu | | 0.97 | 2.85 | 6.25 | 7.14 | 0.89 |
| Wheat/Oats | No-till/Con | 92 bu | 114 bu | | 0.58 | 1.78 | 6.25 | 7.14 | 0.89 |
| Wheat/Oats/Clover | Con/Con/Con | 105 bu | 116 bu | | 0.78 | 2.76 | 6.25 | 6.25 | 0.89 |
| Wheat/Aust. Peas | Con/Con | 112 bu | | | 0.54 | 1.86 | 7.14 | 16.95 | 0.00 |
| Wheat/Clover | Con/Con | 103 bu | | | 0.77 | 2.71 | 7.14 | 9.81 | 0.00 |
| Spring oats | Conventional | 90 bu | | | 1.28 | 3.46 | 2.68 | 6.25 | 0.89 |
| Ryegrass (5)/Wheat | Con/Con | 1090 lbs | 99 bu | | 0.03 | 0.21 | 0.89 | 3.57 | 0.89 |
| Ryegrass (5) | Conventional | 1100 lbs | | | 0.02 | 0.16 | 0.89 | 2.68 | 0.00 |
| Ryegrass (5) | - 75% fert | 882 lbs | | | 0.02 | 0.14 | 0.89 | 1.78 | 0.00 |
| Ryegrass (5) | - 50% fert | 664 lbs | | | 0.02 | 0.12 | 0.89 | 1.78 | 0.00 |
| Ryegrass (5) | (No fall N) | 1030 lbs | | | 0.02 | 0.14 | 0.89 | 1.78 | 0.00 |
| Fescue (5)/Wheat | Con/Con | 1189 lbs | 99 bu | | 0.03 | 0.21 | 0.89 | 3.57 | 0.89 |
| Fescue (5) | Conventional | 1200 lbs | | | 0.02 | 0.16 | 0.89 | 2.68 | 0.00 |
| Fescue (5) | - 75% fert | 962 lbs | | | 0.02 | 0.14 | 0.89 | 1.78 | 0.00 |
| Fescue (5) | - 50% fert | 724 lbs | | | 0.02 | 0.12 | 0.89 | 1.78 | 0.00 |
| Fescue (5) | (No fall N) | 1124 lbs | | | 0.02 | 0.14 | 0.89 | 1.78 | 0.00 |
| Dryland pasture | | 12 AUM | | | 0.03 | 0.14 | 0.89 | 4.46 | 1.78 |
| Irrigated pasture | | 18 AUM | | | 0.03 | 0.13 | 0.89 | 4.46 | 1.78 |
| Dryland hay | | 2.1 T | | | 0.03 | 0.14 | 0.89 | 4.46 | 1.78 |
| Irrigated hay | | 3.2 T | | | 0.03 | 0.13 | 0.89 | 4.46 | 1.78 |
| Continuous corn | | 9.1 T | | | 0.95 | 2.36 | 8.03 | 25.87 | 1.78 |
| Continuous corn | - 75% fert | 8.9 T | | | 0.88 | 2.18 | 6.25 | 18.74 | 0.89 |
| Continuous corn | - 50% fert | 8.7 T | | | 0.81 | 2.00 | 4.46 | 12.49 | 0.89 |
| Corn/Beans | | 9.1 T | 5.9 T | | 1.06 | 2.52 | 6.25 | 9.81 | 1.78 |
| Corn/Beans | - 85% fert | 9.1 T | 5.8 T | | 1.05 | 2.48 | 5.35 | 6.25 | 0.89 |
| Corn/Beans | - 75% fert | 8.8 T | 5.2 T | | 1.02 | 2.40 | 4.46 | 6.25 | 0.89 |
| Corn/Beans | - 50% fert | 8.6 T | 4.5 T | | 0.99 | 2.28 | 3.57 | 2.68 | 0.89 |
| Corn/Beans/Wheat | Winter cover | 9.1 T | 5.9 T | 99 bu | 0.67 | 1.86 | 6.25 | 6.25 | 0.89 |
| Corn/Beans/Wheat | - 85% fert | 9.1 T | 5.8 T | 89 bu | 0.67 | 1.85 | 6.25 | 0.00 | 0.89 |
| Corn/Beans/Wheat | - 75% fert | 8.8 T | 5.3 T | 81 bu | 0.67 | 1.82 | 5.35 | 0.00 | 0.89 |
| Corn/Beans/Wheat | - 50% fert | 8.6 T | 4.6 T | 64 bu | 0.66 | 1.78 | 4.46 | 0.00 | 0.89 |
| Corn/Clover | | 9.1 T | | | 0.52 | 1.73 | 7.14 | 7.14 | 1.78 |
| Corn/Clover | - 75% fert | 8.9 T | | | 0.51 | 1.68 | 6.25 | 0.00 | 0.89 |
| Corn/Clover | - 50% fert | 8.8 T | | | 0.50 | 1.62 | 5.35 | 0.00 | 0.89 |

Table IV-3. Results of EPIC simulations for well-drained terraces (continued).

| Woodburn - 6% slope CROP ROTATION | MGMT | CROP YIELDS Crop 1 | Crop 2 | Crop 3 | Soil Erosion (T) | Runoff Org. N (lb) | Runoff $NO_3$-N (lb) | Leached $NO_3$-N (lb) | Phos. Runoff (lb) |
|---|---|---|---|---|---|---|---|---|---|
| Wheat | Conventional | 99 bu | | | 6.83 | 14.35 | 11.60 | 7.14 | 0.89 |
| Wheat | Reduced till | 99 bu | | | 6.67 | 15.85 | 12.49 | 7.14 | 0.89 |
| Wheat | No-till | 99 bu | | | 0.88 | 2.97 | 15.17 | 6.25 | 0.89 |
| Wheat | (No fall N) | 94 bu | | | 6.86 | 14.24 | 9.81 | 4.46 | 0.00 |
| Wheat/Grass seed | Con/Con | 119 bu | 1560 lbs | | 3.60 | 8.39 | 11.60 | 3.57 | 0.89 |
| Wheat/Grass seed | Con/No-till | 121 bu | 1550 lbs | | 3.17 | 7.77 | 10.71 | 3.57 | 0.89 |
| Wheat/Oats | Con/Con | 90 bu | 114 bu | | 8.21 | 16.49 | 8.92 | 5.35 | 0.89 |
| Wheat/Oats | No-till/Con | 91 bu | 115 bu | | 4.89 | 10.55 | 8.92 | 5.35 | 0.89 |
| Wheat/Oats/Clover | Con/Con/Con | 105 bu | 117 bu | | 6.57 | 15.63 | 7.14 | 4.46 | 0.89 |
| Wheat/Clover | Con/Con | 104 bu | | | 6.45 | 15.43 | 9.81 | 7.14 | 0.89 |
| Wheat/Aust. Peas | Con/Con | 113 bu | | | 4.55 | 10.72 | 9.81 | 13.38 | 0.89 |
| Ryegrass (5)/Wheat | Con/Con | 1090 lbs | 99 bu | | 0.31 | 1.41 | 1.78 | 3.57 | 0.89 |
| Ryegrass (5) | Conventional | 1100 lbs | | | 0.20 | 1.05 | 1.78 | 2.68 | 0.89 |
| Ryegrass (5) | - 75% fert | 878 lbs | | | 0.20 | 0.94 | 1.78 | 1.78 | 0.00 |
| Ryegrass (5) | - 50% fert | 660 lbs | | | 0.20 | 0.82 | 1.78 | 1.78 | 0.00 |
| Ryegrass (5) | (No fall N) | 1026 lbs | | | 0.20 | 0.94 | 1.78 | 1.78 | 0.00 |
| Fescue (5)/Wheat | Con/Con | 1189 lbs | 99 bu | | 0.31 | 1.41 | 1.78 | 3.57 | 0.89 |
| Fescue (5) | Conventional | 1200 lbs | | | 0.20 | 1.05 | 1.78 | 2.68 | 0.89 |
| Fescue (5) | - 75% fert | 958 lbs | | | 0.20 | 0.94 | 1.78 | 1.78 | 0.00 |
| Fescue (5) | - 50% fert | 720 lbs | | | 0.20 | 0.82 | 1.78 | 1.78 | 0.00 |
| Fescue (5) | (No fall N) | 1118 lbs | | | 0.20 | 0.94 | 1.78 | 1.78 | 0.00 |
| Dryland pasture | | 12 AUM | | | 0.27 | 0.97 | 0.89 | 3.57 | 1.78 |
| Irrigated pasture | | 18 AUM | | | 0.27 | 0.90 | 0.89 | 4.46 | 1.78 |
| Dryland hay | | 2.1 T | | | 0.27 | 0.97 | 0.89 | 3.57 | 1.78 |
| Irrigated hay | | 3.2 T | | | 0.27 | 0.90 | 0.89 | 4.46 | 1.78 |
| Continuous corn | | 9.1 T | | | 8.05 | 14.70 | 10.71 | 24.09 | 1.78 |
| Continuous corn | - 75% fert | 8.9 T | | | 7.45 | 13.59 | 8.03 | 17.84 | 0.89 |
| Continuous corn | - 50% fert | 8.7 T | | | 6.84 | 12.48 | 5.35 | 11.60 | 0.89 |
| Corn/Beans | | 9.1 T | 5.9 T | | 8.99 | 15.78 | 8.92 | 8.03 | 1.78 |
| Corn/Beans | - 85% fert | 9.1 T | 5.8 T | | 8.86 | 15.51 | 7.14 | 5.35 | 1.78 |
| Corn/Beans | - 75% fert | 8.8 T | 5.2 T | | 8.67 | 15.06 | 6.25 | 4.46 | 0.89 |
| Corn/Beans | - 50% fert | 8.5 T | 4.5 T | | 8.35 | 14.33 | 4.46 | 1.78 | 0.89 |
| Corn/Beans/Wheat | Winter cover | 9.1 T | 5.9 T | 98 bu | 5.84 | 11.50 | 8.92 | 4.46 | 0.89 |
| Corn/Beans/Wheat | - 75% fert | 8.8 T | 5.3 T | 81 bu | 5.79 | 11.25 | 7.14 | 0.00 | 0.89 |
| Corn/Beans/Wheat | - 50% fert | 8.6 T | 4.6 T | 63 bu | 5.73 | 11.00 | 6.25 | 0.00 | 0.89 |
| Corn/Clover | | 9.1 T | | | 4.40 | 10.54 | 9.81 | 5.35 | 1.78 |
| Corn/Clover | - 75% fert | 8.9 T | | | 4.33 | 10.21 | 8.03 | 0.00 | 0.89 |
| Corn/Clover | - 50% fert | 8.8 T | | | 4.25 | 9.88 | 7.14 | 0.00 | 0.89 |

Table IV-3. Results of EPIC simulations for well-drained terraces (continued).

Woodburn - 10% slope

| CROP ROTATION | MGMT | CROP YIELDS Crop 1 | Crop 2 | Crop 3 | Soil Erosion (T) | Runoff Org. N (lb) | Runoff $NO_3$-N (lb) | Leached $NO_3$-N (lb) | Phos. Runoff (lb) |
|---|---|---|---|---|---|---|---|---|---|
| Wheat | Conventional | 98 bu | | | 16.15 | 30.46 | 14.27 | 6.25 | 0.89 |
| Wheat | Reduced till | 98 bu | | | 15.74 | 33.97 | 14.27 | 6.25 | 0.89 |
| Wheat | No-till | 98 bu | | | 2.08 | 6.29 | 16.95 | 5.35 | 0.89 |
| Wheat | (No fall N) | 93 bu | | | 16.24 | 30.24 | 12.49 | 3.57 | 0.00 |
| Wheat/Grass seed | Con/No-till | 120 bu | 1540 lbs | | 7.26 | 15.71 | 12.49 | 3.57 | 0.89 |
| Wheat/Oats | Con/Con | 89 bu | 113 bu | | 19.28 | 34.88 | 9.81 | 5.35 | 0.89 |
| Wheat/Oats | No-till/Con | 90 bu | 114 bu | | 11.54 | 22.04 | 9.81 | 5.35 | 1.78 |
| Wheat/Oats/Clover | Con/Con/Con | 105 bu | 116 bu | | 15.56 | 32.99 | 8.03 | 4.46 | 0.89 |
| Wheat/Aust. Peas | Con/Con | 112 bu | | | 10.76 | 22.79 | 10.71 | 12.49 | 0.89 |
| Ryegrass (5)/Wheat | Con/Con | 1086 lbs | 99 bu | | 0.79 | 3.04 | 1.78 | 3.57 | 0.89 |
| Ryegrass (5) | Conventional | 1092 lbs | | | 0.51 | 2.28 | 2.68 | 2.68 | 0.89 |
| Ryegrass (5) | - 75% fert | 876 lbs | | | 0.51 | 2.02 | 2.68 | 1.78 | 0.00 |
| Ryegrass (5) | - 50% fert | 658 lbs | | | 0.51 | 1.77 | 2.68 | 1.78 | 0.00 |
| Ryegrass (5) | (No fall N) | 1024 lbs | | | 0.51 | 2.02 | 2.68 | 1.78 | 0.00 |
| Fescue (5)/Wheat | Con/Con | 1185 lbs | 99 bu | | 0.79 | 3.04 | 1.78 | 3.57 | 0.89 |
| Fescue (5) | Conventional | 1192 lbs | | | 0.51 | 2.28 | 2.68 | 2.68 | 0.89 |
| Fescue (5) | - 75% fert | 956 lbs | | | 0.51 | 2.02 | 2.68 | 1.78 | 0.00 |
| Fescue (5) | - 50% fert | 718 lbs | | | 0.51 | 1.77 | 2.68 | 1.78 | 0.00 |
| Fescue (5) | (No fall N) | 1116 lbs | | | 0.51 | 2.02 | 2.68 | 1.78 | 0.00 |
| Dryland pasture | | 12 AUM | | | 0.69 | 2.12 | 1.78 | 3.57 | 2.68 |
| Irrigated pasture | | 18 AUM | | | 0.67 | 1.96 | 1.78 | 4.46 | 2.68 |
| Dryland hay | | 2.1 T | | | 0.69 | 2.12 | 1.78 | 3.57 | 2.68 |
| Irrigated hay | | 3.2 T | | | 0.67 | 1.96 | 1.78 | 4.46 | 2.68 |

Table IV-3. Results of EPIC simulations for well-drained terraces (continued).

| Woodburn - 15% slope | | ----- CROP YIELDS ---- | | | Soil Erosion | --- Runoff --- | | Leached | Phos. Runoff |
|---|---|---|---|---|---|---|---|---|---|
| CROP ROTATION | MGMT | Crop 1 | Crop 2 | Crop 3 | (T) | Org. N (lb) | $NO_3$-N (lb) | $NO_3$-N (lb) | (lb) |
| Wheat | Conventional | 97 bu | | | 33.56 | 56.42 | 15.17 | 5.35 | 0.89 |
| Wheat | Reduced till | 97 bu | | | 32.11 | 59.20 | 15.17 | 5.35 | 0.89 |
| Wheat | No-till | 97 bu | | | 4.31 | 11.90 | 18.74 | 5.35 | 1.78 |
| Wheat | (No fall N) | 92 bu | | | 33.75 | 56.02 | 13.38 | 3.57 | 0.00 |
| Wheat/Grass seed | Con/No-till | 119 bu | 1520 lbs | | 14.40 | 28.59 | 13.38 | 2.68 | 0.89 |
| Wheat/Oats | Con/Con | 88 bu | 110 bu | | 40.90 | 63.69 | 10.71 | 5.35 | 0.89 |
| Wheat/Oats | Not/Con | 89 bu | 112 bu | | 23.44 | 41.33 | 10.71 | 4.46 | 1.78 |
| Wheat/Oats/Clover | Con/Con/Con | 104 bu | 113 bu | | 32.42 | 60.74 | 8.92 | 3.57 | 0.89 |
| Wheat/Aust. Peas | Con/Con | 112 bu | | | 22.18 | 44.19 | 11.60 | 11.60 | 0.89 |
| Ryegrass (5)/Wheat | Con/Con | 1084 lbs | 99 bu | | 1.70 | 5.78 | 2.68 | 3.57 | 0.89 |
| Ryegrass (5) | Conventional | 1088 lbs | | | 1.10 | 4.34 | 3.57 | 2.68 | 0.89 |
| Ryegrass (5) | - 75% fert | 872 lbs | | | 1.10 | 3.86 | 3.57 | 1.78 | 0.00 |
| Ryegrass (5) | - 50% fert | 656 lbs | | | 1.10 | 3.38 | 2.68 | 1.78 | 0.00 |
| Ryegrass (5) | (No fall N) | 1020 lbs | | | 1.10 | 3.86 | 2.68 | 1.78 | 0.00 |
| Fescue (5)/Wheat | Con/Con | 1183 lbs | 99 bu | | 1.70 | 5.78 | 2.68 | 3.57 | 0.89 |
| Fescue (5) | Conventional | 1188 lbs | | | 1.10 | 4.34 | 3.57 | 2.68 | 0.89 |
| Fescue (5) | - 75% fert | 952 lbs | | | 1.10 | 3.86 | 3.57 | 1.78 | 0.00 |
| Fescue (5) | - 50% fert | 716 lbs | | | 1.10 | 3.38 | 2.68 | 1.78 | 0.00 |
| Fescue (5) | (No fall N) | 1112 lbs | | | 1.10 | 3.86 | 2.68 | 1.78 | 0.00 |
| Dryland pasture | | 12 AUM | | | 1.47 | 4.08 | 1.78 | 3.57 | 2.68 |
| Dryland hay | | 2.1 T | | | 1.47 | 4.08 | 1.78 | 3.57 | 2.68 |

farms face limited production options. Dayton and Amity soils make up the acreage on this farm and, consistent with the valley as a whole, ten percent of the Amity soil is assumed to be tiled and able to produce vegetable crops. On these tile-drained acres, leaching of nitrogen is a problem. EPIC predicts more than 20 pounds per acre leached from growing grains or vegetables, even with winter cover (table IV-4). For the remaining 976 undrained acres, however, grass seed crops tend to be most suitable. Both soil types are subject to surface runoff of nitrates but not to groundwater leaching.

Finally, the foothill farm of the Jory soil type with three different slopes faces limited production options (table IV-5). Simulated erosion rates and leaching are high on intensively cropped lands, and nitrate leaching can be a problem even for perennial grass seed production. However, it is estimated that under an intensive Christmas tree production with grass strips, erosion can be curtailed, although with nitrate leaching of 24 pounds per acre, one of the highest rates of leaching of any crop-soil combination.

**B. Present situation.**

Results of the linear programming (GAMS) models for the unrestricted farms are presented in this section. They represent the most profitable crop mixes given the resources, soils, and production constraints facing each farm. Effluent is not considered in the decision, and

Table IV-4. Results of EPIC simulations for poorly-drained terraces.

| Amity - 1% slope<br>CROP ROTATION | MGMT | CROP YIELDS<br>Crop 1 | Crop 2 | Crop 3 | Soil Erosion (T) | Runoff Org. N (lb) | Runoff $NO_3$-N (lb) | Leached $NO_3$-N (lb) | Phos. Runoff (lb) |
|---|---|---|---|---|---|---|---|---|---|
| Wheat | Conventional | 100 bu | | | 1.29 | 4.34 | 10.71 | 25.87 | 0.89 |
| Wheat | Reduced till | 100 bu | | | 1.25 | 4.58 | 11.60 | 25.87 | 0.89 |
| Wheat | No-till | 99 bu | | | 0.16 | 0.82 | 13.38 | 24.09 | 1.78 |
| Wheat | (No fall N) | 95 bu | | | 1.29 | 0.00 | 10.71 | 19.63 | 0.00 |
| Wheat/Grass seed | Con/Con | 122 bu | 1650 lbs | | 0.67 | 2.43 | 11.60 | 13.38 | 0.89 |
| Wheat/Grass seed | Con/No-till | 124 bu | 1650 lbs | | 0.59 | 2.18 | 9.81 | 12.49 | 0.89 |
| Wheat/Oats | Con/Con | 92 bu | 111 bu | | 1.51 | 4.93 | 8.03 | 20.52 | 0.89 |
| Wheat/Oats | Not/Con | 92 bu | 112 bu | | 0.87 | 2.94 | 8.03 | 20.52 | 1.78 |
| Wheat/Oats/Clover | Con/Con/Con | 103 bu | 117 bu | | 1.23 | 4.59 | 7.14 | 31.23 | 0.89 |
| Wheat/Aust. Peas | Con/Con | 111 bu | | | 0.87 | 3.16 | 8.92 | 53.53 | 0.89 |
| Wheat/Clover | Con/Con | 102 bu | | | 1.23 | 4.59 | 8.03 | 40.15 | 0.89 |
| Spring oats | Conventional | 90 bu | | | 2.06 | 6.29 | 3.57 | 15.17 | 1.78 |
| Annual ryegrass | Conventional | 1800 lbs | | | 0.09 | 0.43 | 8.92 | 2.68 | 0.00 |
| Annual ryegrass | - 75% fert | 1430 lbs | | | 0.09 | 0.41 | 7.14 | 1.78 | 0.00 |
| Annual ryegrass | - 50% fert | 1090 lbs | | | 0.09 | 0.40 | 5.35 | 1.78 | 0.00 |
| Annual ryegrass | -(No fall N) | 1640 lbs | | | 0.09 | 0.42 | 7.14 | 1.78 | 0.00 |
| Annual ryegrass | No-till | 1780 lbs | | | 0.09 | 0.66 | 9.81 | 2.68 | 0.89 |
| Annual ryegrass | - 75% fert | 1407 lbs | | | 0.09 | 0.57 | 8.03 | 1.78 | 0.89 |
| Annual ryegrass | - 50% fert | 1067 lbs | | | 0.09 | 0.48 | 6.25 | 1.78 | 0.89 |
| Annual ryegrass | -(No fall N) | 1607 lbs | | | 0.09 | 0.65 | 7.14 | 1.78 | 0.89 |
| Ryegrass (5)/Wheat | Con/Con | 1140 lbs | 100 bu | | 0.11 | 0.58 | 4.46 | 8.03 | 1.78 |
| Ryegrass (5) | Conventional | 1100 lbs | | | 0.07 | 0.44 | 6.25 | 5.35 | 0.89 |
| Ryegrass (5) | - 75% fert | 884 lbs | | | 0.07 | 0.39 | 4.46 | 4.46 | 0.89 |
| Ryegrass (5) | - 50% fert | 668 lbs | | | 0.07 | 0.34 | 3.57 | 3.57 | 0.89 |
| Ryegrass (5) | (No fall N) | 1038 lbs | | | 0.07 | 0.41 | 5.35 | 3.57 | 0.00 |
| Fescue (5)/Wheat | Con/Con | 1240 lbs | 100 bu | | 0.11 | 0.58 | 4.46 | 8.03 | 1.78 |
| Fescue (5) | Conventional | 1200 lbs | | | 0.07 | 0.44 | 6.25 | 5.35 | 0.89 |
| Fescue (5) | - 75% fert | 964 lbs | | | 0.07 | 0.39 | 4.46 | 4.46 | 0.89 |
| Fescue (5) | - 50% fert | 728 lbs | | | 0.07 | 0.34 | 3.57 | 3.57 | 0.89 |
| Fescue (5) | (No fall N) | 1132 lbs | | | 0.07 | 0.41 | 5.35 | 3.57 | 0.00 |
| Dryland pasture | | 10 AUM | | | 0.09 | 0.40 | 2.68 | 7.14 | 4.46 |
| Irrigated pasture | | 16 AUM | | | 0.09 | 0.37 | 2.68 | 8.92 | 3.57 |
| Dryland hay | | 2.1 T | | | 0.09 | 0.40 | 2.68 | 7.14 | 4.46 |
| Irrigated hay | | 2.8 T | | | 0.09 | 0.37 | 2.68 | 8.92 | 3.57 |
| Continuous corn | | 9.1 T | | | 1.34 | 3.75 | 9.81 | 56.21 | 1.78 |
| Continuous corn | - 75% fert | 9.0 T | | | 1.24 | 3.47 | 8.03 | 33.90 | 0.89 |
| Continuous corn | - 50% fert | 8.9 T | | | 1.14 | 3.19 | 6.25 | 11.60 | 0.89 |
| Corn/Beans | | 9.1 T | 5.9 T | | 1.49 | 4.00 | 8.03 | 28.55 | 1.78 |
| Corn/Beans | - 75% fert | 8.9 T | 5.3 T | | 1.42 | 3.80 | 6.25 | 18.74 | 0.89 |
| Corn/Beans | - 50% fert | 8.7 T | 4.7 T | | 1.36 | 3.60 | 5.35 | 9.81 | 0.89 |
| Corn/Beans/Wheat | Winter cover | 9.1 T | 5.9 T | 97 bu | 1.03 | 3.08 | 8.03 | 20.52 | 1.78 |
| Corn/Beans/Wheat | - 75% fert | 9.0 T | 5.4 T | 79 bu | 1.01 | 3.00 | 7.14 | 13.38 | 0.89 |
| Corn/Beans/Wheat | - 50% fert | 8.8 T | 4.9 T | 60 bu | 1.00 | 2.92 | 6.25 | 6.25 | 0.89 |
| Corn/Clover | | 9.1 T | | | 0.77 | 2.82 | 9.81 | 27.66 | 1.78 |
| Corn/Clover | - 75% fert | 9.1 T | | | 0.75 | 2.71 | 8.03 | 19.63 | 0.89 |
| Corn/Clover | - 50% fert | 9.0 T | | | 0.73 | 2.60 | 7.14 | 11.60 | 0.89 |
| Corn/Aust. Peas | | 8.6 T | | | 0.74 | 2.65 | 9.81 | 51.75 | 1.78 |

Table IV-4. Results of EPIC simulations for poorly-drained terraces (continued).

------

| Dayton - 1% slope | | | | | Soil | --- Runoff --- | | Leached | Phos. |
|---|---|---|---|---|---|---|---|---|---|
| | | ----- CROP YIELDS ---- | | | Erosion | Org. N | $NO_3$-N | $NO_3$-N | Runoff |
| CROP ROTATION | MGMT | Crop 1 | Crop 2 | Crop 3 | (T) | (lb) | (lb) | (lb) | (lb) |
| Wheat | Conventional | 50 bu | | | 1.53 | 4.97 | 16.06 | 16.06 | 0.89 |
| Wheat | Reduced till | 50 bu | | | 1.50 | 5.29 | 16.06 | 16.06 | 0.89 |
| Wheat | No-till | 49 bu | | | 0.20 | 0.96 | 17.84 | 15.17 | 1.78 |
| Wheat/Grass seed | Con/Con | 59 bu | 1650 lbs | | 0.81 | 2.89 | 16.06 | 8.92 | 0.89 |
| Wheat/Grass seed | Con/No-till | 61 bu | 1640 lbs | | 0.72 | 2.67 | 14.27 | 8.03 | 0.89 |
| Wheat/Oats | Con/Con | 45 bu | 62 bu | | 1.88 | 5.81 | 11.60 | 13.38 | 0.89 |
| Wheat/Oats | No-till/Con | 46 bu | 63 bu | | 1.15 | 3.82 | 10.71 | 13.38 | 1.78 |
| Wheat/Oats/Clover | Con/Con/Con | 55 bu | 78 bu | | 1.23 | 4.59 | 7.14 | 31.23 | 0.89 |
| Annual ryegrass | Conventional | 1800 lbs | | | 0.11 | 0.55 | 12.49 | 1.78 | 0.00 |
| Annual ryegrass | - 75% fert | 1420 lbs | | | 0.11 | 0.54 | 9.81 | 0.89 | 0.00 |
| Annual ryegrass | - 50% fert | 1070 lbs | | | 0.12 | 0.54 | 8.03 | 0.89 | 0.00 |
| Annual ryegrass | -(No fall N) | 1610 lbs | | | 0.12 | 0.54 | 12.49 | 0.89 | 0.00 |
| Annual ryegrass | No-till | 1770 lbs | | | 0.11 | 0.70 | 14.27 | 1.78 | 0.89 |
| Annual ryegrass | - 85% fert | 1570 lbs | | | 0.11 | 0.64 | 12.49 | 0.89 | 0.89 |
| Annual ryegrass | - 75% fert | 1398 lbs | | | 0.11 | 0.63 | 10.71 | 0.89 | 0.00 |
| Annual ryegrass | - 50% fert | 1054 lbs | | | 0.12 | 0.56 | 7.14 | 0.89 | 0.00 |
| Annual ryegrass | -(No fall N) | 1581 lbs | | | 0.12 | 0.68 | 14.27 | 0.89 | 0.89 |
| Ryegrass (5)/Wheat | Con/Con | 860 lbs | 51 bu | | 0.06 | 0.41 | 1.78 | 6.25 | 0.89 |
| Ryegrass (5) | Conventional | 850 lbs | | | 0.04 | 0.30 | 1.78 | 3.57 | 0.89 |
| Ryegrass (5) | - 75% fert | 680 lbs | | | 0.04 | 0.28 | 1.78 | 2.68 | 0.00 |
| Ryegrass (5) | - 50% fert | 512 lbs | | | 0.04 | 0.26 | 1.78 | 2.68 | 0.00 |
| Ryegrass (5) | (No fall N) | 796 lbs | | | 0.04 | 0.29 | 1.78 | 2.68 | 0.00 |
| Fescue (5)/Wheat | Con/Con | 936 lbs | 51 bu | | 0.06 | 0.41 | 1.78 | 6.25 | 0.89 |
| Fescue (5) | Conventional | 926 lbs | | | 0.04 | 0.30 | 1.78 | 3.57 | 0.89 |
| Fescue (5) | - 75% fert | 740 lbs | | | 0.04 | 0.28 | 1.78 | 2.68 | 0.00 |
| Fescue (5) | - 50% fert | 558 lbs | | | 0.04 | 0.26 | 1.78 | 2.68 | 0.00 |
| Fescue (5) | (No fall N) | 868 lbs | | | 0.04 | 0.29 | 1.78 | 2.68 | 0.00 |
| Dryland pasture | | 8 AUM | | | 0.05 | 0.31 | 0.89 | 7.14 | 1.78 |
| Dryland hay | | 1.4 T | | | 0.05 | 0.31 | 0.89 | 7.14 | 1.78 |
| Unimproved range | | 7 AUM | | | 0.01 | 0.05 | 0.89 | 0.89 | 0.00 |

Table IV-5. Results of EPIC simulations for well-drained foothills.

Jory - 5% slope

| CROP ROTATION | MGMT | CROP YIELDS Crop 1 | Crop 2 | Crop 3 | Soil Erosion (T) | Runoff Org. N (lb) | Runoff $NO_3$-N (lb) | Leached $NO_3$-N (lb) | Phos. Runoff (lb) |
|---|---|---|---|---|---|---|---|---|---|
| Wheat | Conventional | 80 bu | | | 3.89 | 16.75 | 7.14 | 66.91 | 0.89 |
| Wheat | Reduced till | 80 bu | | | 3.81 | 18.38 | 7.14 | 67.81 | 0.89 |
| Wheat | No-till | 81 bu | | | 0.56 | 3.54 | 8.03 | 63.35 | 0.89 |
| Wheat/Grass seed | Con/Con | 99 bu | 1590 lbs | | 1.96 | 9.39 | 6.25 | 38.36 | 0.00 |
| Wheat/Grass seed | Con/No-till | 99 bu | 1580 lbs | | 1.82 | 9.09 | 6.25 | 38.36 | 0.89 |
| Wheat/Oats | Con/Con | 78 bu | 84 bu | | 3.81 | 16.31 | 4.46 | 55.32 | 0.89 |
| Wheat/Oats | No-till/Con | 79 bu | 85 bu | | 2.29 | 10.68 | 4.46 | 53.53 | 0.89 |
| Wheat/Oats/Clover | Con/Con/Con | 65 bu | 83 bu | | 3.00 | 14.52 | 3.57 | 77.62 | 0.00 |
| Wheat/Clover | Con/Con | 65 bu | | | 3.25 | 15.45 | 5.35 | 90.11 | 0.89 |
| Spring oats | Conventional | 72 bu | | | 5.02 | 19.99 | 1.78 | 42.82 | 0.89 |
| Ryegrass (5)/Wheat | Con/Con | 990 lbs | 87 bu | | 0.30 | 2.29 | 2.68 | 18.74 | 0.89 |
| Ryegrass (5) | Conventional | 1000 lbs | | | 0.19 | 1.68 | 2.68 | 10.71 | 0.89 |
| Ryegrass (5) | - 75% fert | 816 lbs | | | 0.19 | 1.55 | 1.78 | 8.03 | 0.89 |
| Ryegrass (5) | - 50% fert | 630 lbs | | | 0.19 | 1.43 | 1.78 | 6.25 | 0.89 |
| Ryegrass (5) | (No fall N) | 956 lbs | | | 0.19 | 1.62 | 2.68 | 6.25 | 0.00 |
| Fescue (5)/Wheat | Con/Con | 1079 lbs | 87 bu | | 0.30 | 2.29 | 2.68 | 18.74 | 0.89 |
| Fescue (5) | Conventional | 1090 lbs | | | 0.19 | 1.68 | 2.68 | 10.71 | 0.89 |
| Fescue (5) | - 75% fert | 889 lbs | | | 0.19 | 1.55 | 1.78 | 8.03 | 0.89 |
| Fescue (5) | - 50% fert | 687 lbs | | | 0.19 | 1.43 | 1.78 | 6.25 | 0.89 |
| Fescue (5) | (No fall N) | 1042 lbs | | | 0.19 | 1.62 | 2.68 | 6.25 | 0.00 |
| Dryland pasture | | 8 AUM | | | 0.29 | 1.81 | 1.78 | 17.84 | 2.68 |
| Dryland hay | | 1.4 T | | | 0.29 | 1.81 | 1.78 | 17.84 | 2.68 |
| Unimproved range | | 6 AUM | | | 0.07 | 0.38 | 0.89 | 7.14 | 0.00 |
| Christmas trees | | 1280 trees | | | 0.08 | 0.46 | 0.89 | 24.98 | 0.00 |

Table IV-5. Results of EPIC simulations for well-drained foothills (continued).

| Jory - 10% slope | | ----- CROP YIELDS ---- | | | Soil Erosion | --- Runoff --- | | Leached | Phos. Runoff |
|---|---|---|---|---|---|---|---|---|---|
| CROP ROTATION | MGMT | Crop 1 | Crop 2 | Crop 3 | (T) | Org. N (lb) | $NO_3$-N (lb) | $NO_3$-N (lb) | (lb) |
| Wheat | Conventional | 79 bu | | | 12.61 | 46.08 | 8.92 | 66.02 | 0.89 |
| Wheat | Reduced till | 79 bu | | | 12.26 | 51.61 | 8.92 | 66.02 | 0.89 |
| Wheat | No-till | 81 bu | | | 1.80 | 9.90 | 10.71 | 61.56 | 0.89 |
| Wheat/Grass seed | Con/Con | 98 bu | 1580 lbs | | 6.22 | 25.27 | 8.03 | 36.58 | 0.89 |
| Wheat/Grass seed | Con/No-till | 98 bu | 1560 lbs | | 5.73 | 24.05 | 8.03 | 36.58 | 0.89 |
| Wheat/Oats | Con/Con | 77 bu | 82 bu | | 12.48 | 44.81 | 4.46 | 53.53 | 0.89 |
| Wheat/Oats | No-till/Con | 78 bu | 84 bu | | 7.53 | 28.81 | 5.35 | 51.75 | 0.89 |
| Wheat/Oats/Clover | Con/Con/Con | 65 bu | 82 bu | | 9.90 | 39.60 | 4.46 | 75.84 | 0.89 |
| Wheat/Clover | Con/Con | 57 bu | | | 10.56 | 42.47 | 6.25 | 89.22 | 0.89 |
| Ryegrass (5)/Wheat | Con/Con | 990 lbs | 87 bu | | 0.98 | 6.32 | 3.57 | 17.84 | 0.89 |
| Ryegrass (5) | Conventional | 996 lbs | | | 0.62 | 4.71 | 3.57 | 9.81 | 0.89 |
| Ryegrass (5) | - 75% fert | 812 lbs | | | 0.62 | 4.36 | 2.68 | 7.14 | 0.89 |
| Ryegrass (5) | - 50% fert | 628 lbs | | | 0.62 | 4.01 | 1.78 | 5.35 | 0.89 |
| Ryegrass (5) | (No fall N) | 952 lbs | | | 0.62 | 4.56 | 3.57 | 5.35 | 0.00 |
| Fescue (5)/Wheat | Con/Con | 1079 lbs | 87 bu | | 0.98 | 6.32 | 3.57 | 17.84 | 0.89 |
| Fescue (5) | Conventional | 1086 lbs | | | 0.62 | 4.71 | 3.57 | 9.81 | 0.89 |
| Fescue (5) | - 75% fert | 885 lbs | | | 0.62 | 4.36 | 2.68 | 7.14 | 0.89 |
| Fescue (5) | - 50% fert | 685 lbs | | | 0.62 | 4.01 | 1.78 | 5.35 | 0.89 |
| Fescue (5) | (No fall N) | 1038 lbs | | | 0.62 | 4.56 | 3.57 | 5.35 | 0.00 |
| Dryland pasture | | 8 AUM | | | 0.94 | 5.06 | 1.78 | 17.84 | 3.57 |
| Dryland hay | | 1.4 T | | | 0.94 | 5.06 | 1.78 | 17.84 | 3.57 |
| Unimproved range | | 6 AUM | | | 0.21 | 1.10 | 0.89 | 6.25 | 0.00 |
| Christmas trees | | 1280 trees | | | 0.29 | 1.37 | 0.89 | 24.09 | 0.00 |

Table IV-5. Results of EPIC simulations for well-drained foothills (continued).

------

| Jory - 15% slope<br>CROP ROTATION | MGMT | ----- CROP YIELDS ----<br>Crop 1 | Crop 2 | Crop 3 | Soil Erosion (T) | --- Runoff ---<br>Org. N (lb) | $NO_3$-N (lb) | Leached $NO_3$-N (lb) | Phos. Runoff (lb) |
|---|---|---|---|---|---|---|---|---|---|
| Wheat | Conventional | 78 bu | | | 26.25 | 80.46 | 9.81 | 64.24 | 0.89 |
| Wheat | Reduced till | 78 bu | | | 25.36 | 89.39 | 9.81 | 64.24 | 0.89 |
| Wheat | No-till | 80 bu | | | 3.73 | 18.78 | 11.60 | 60.67 | 1.78 |
| Wheat/Oats | Con/Con | 76 bu | 80 bu | | 26.03 | 78.25 | 5.35 | 52.64 | 0.89 |
| Wheat/Oats | No-till/Con | 77 bu | 83 bu | | 15.69 | 54.07 | 5.35 | 51.75 | 0.89 |
| Wheat/Oats/Clover | Con/Con/Con | 64 bu | 81 bu | | 20.84 | 71.22 | 4.46 | 74.05 | 0.89 |
| Wheat/Clover | Con/Con | 56 bu | | | 22.24 | 75.18 | 6.25 | 87.43 | 0.89 |
| Ryegrass (5)/Wheat | Con/Con | 986 lbs | 87 bu | | 2.06 | 11.79 | 3.57 | 17.84 | 0.89 |
| Ryegrass (5) | Conventional | 994 lbs | | | 1.32 | 8.91 | 3.57 | 9.81 | 0.89 |
| Ryegrass (5) | - 75% fert | 810 lbs | | | 1.32 | 8.25 | 2.68 | 7.14 | 0.89 |
| Ryegrass (5) | - 50% fert | 626 lbs | | | 1.32 | 7.59 | 1.78 | 5.35 | 0.89 |
| Ryegrass (5) | (No fall N) | 948 lbs | | | 1.32 | 8.63 | 3.57 | 5.35 | 0.00 |
| Fescue (5)/Wheat | Con/Con | 1075 lbs | 87 bu | | 2.06 | 11.79 | 3.57 | 17.84 | 0.89 |
| Fescue (5) | Conventional | 1083 lbs | | | 1.32 | 8.91 | 3.57 | 9.81 | 0.89 |
| Fescue (5) | - 75% fert | 883 lbs | | | 1.32 | 8.25 | 2.68 | 7.14 | 0.89 |
| Fescue (5) | - 50% fert | 682 lbs | | | 1.32 | 7.59 | 1.78 | 5.35 | 0.89 |
| Fescue (5) | (No fall N) | 1033 lbs | | | 1.32 | 8.63 | 3.57 | 5.35 | 0.00 |
| Dryland pasture | | 8 AUM | | | 1.96 | 9.58 | 2.68 | 17.84 | 3.57 |
| Dryland hay | | 1.4 T | | | 1.96 | 9.58 | 2.68 | 17.84 | 3.57 |
| Unimproved range | | 6 AUM | | | 0.45 | 2.14 | 0.89 | 6.25 | 0.00 |
| Christmas trees | | 1280 trees | | | 0.63 | 2.68 | 0.89 | 24.09 | 0.00 |

remains unvalued.

The 450-acre well-drained bottomland farm (table IV-6) is found to be profitable under intensive crop rotation, including 167 acres in a corn and beans rotation, another 89 acres in a corn/bean/wheat rotation with a winter clover cover, 90 acres in perennial ryegrass seed, 54 acres in tall fescue seed, and 49 acres in no-till wheat. The well-drained characteristics of the soil and intensive production result in high leaching of nitrates -- more than 16 pounds per acre averaged over the crop mix. Surface runoff and erosion, however, are not significant problems.

Table IV-6. Optimal solution for unrestricted well-drained bottomland farm (450 acres).

| | |
|---|---|
| Total Farm Profit: | $ 66,297.29 |
| Per Acre | 147.33 |
| Crop rotations: | Acres: |
| Corn/Beans | 167.4 |
| Perennial ryegrass seed | 90.0 |
| Corn/Beans/Wheat (w/cover) | 89.2 |
| Tall fescue seed | 54.0 |
| Wheat (no-till) | 49.5 |
| Per acre effluent: | |
| Soil erosion (t) | 0.30 |
| Organic N lost to sediment (lbs) | 0.75 |
| NO3 lost to runoff (lbs) | 1.86 |
| NO3 leached beyond root zone (lbs) | 16.64 |
| Phosphorus lost to runoff (lbs) | 0.61 |

As noted earlier, the poorly drained farm of the river bottoms has fewer cropping options. The profit maximizing acreage from the LP solution is devoted entirely to grass seed production, the majority of it in annual ryegrass (table IV-7). Leaching of nitrates is less than 3 pounds per acre, but the surface loss of nitrates and organic N exceeds 10 pounds per acre.

Table IV-7. Optimal solution for unrestricted poorly-drained bottomland farm (200 acres).

| | |
|---|---|
| Total Farm Profit: | $ 24,995.04 |
| Per Acre | 124.98 |
| Crop rotations: | Acres: |
| Annual ryegrass seed (no-till) | 136.0 |
| Perennial ryegrass seed | 40.0 |
| Tall fescue seed | 24.0 |
| Per acre effluent: | |
| Soil erosion (t) | 0.07 |
| Organic N lost to sediment (lbs) | 0.53 |
| NO3 lost to runoff (lbs) | 10.27 |
| NO3 leached beyond root zone (lbs) | 2.92 |
| Phosphorus lost to runoff (lbs) | 0.89 |

The 500-acre well-drained terrace farm encompasses four different slope classes and enjoys considerable flexibility in crop and rotation selection. The acreage is split between corn and beans (201 acres), wheat-annual ryegrass under no-till (139), perennial ryegrass (100) and tall fescue (60) (table IV-8). The effluent associated with this crop mix amounts to a moderate per-acre level of nitrate leaching (4.47 pounds), reasonably high runoff of organic-N and nitrates (8.92 pounds), and nearly 2 tons per acre of soil erosion. The soil erosion is due primarily to vegetable production on 6% slope lands, which results in about 9 tons per acre in erosion.

One interesting aspect of the LP solution for this terrace farm is that the profit maximizing production of vegetables involves 15% less nitrogen fertilizer input than is used by the "typical" Willamette Valley vegetable farmer. In addition to the 15% reduced-N case, both a 25% and 50% reduced-N were considered for vegetable production.

Table IV-8. Optimal solution for unrestricted well-drained terrace land farm (500 acres).

| | |
|---|---|
| Total Farm Profit: | $ 71,354.31 |
| Per Acre | 142.71 |
| | |
| Crop rotations (by slope class): | Acres: |
| (1%) | |
| Wheat/annual ryegrass seed (no-till) | 138.8 |
| Corn/Beans (85% fertilizer)* | 121.2 |
| Perennial ryegrass seed | 100.0 |
| Tall fescue seed | 13.0 |
| (6%) | |
| Corn/Beans (85% fertilizer)* | 80.0 |
| (10%) | |
| Tall fescue seed | 32.0 |
| (15%) | |
| Tall fescue seed | 15.0 |
| | |
| Per acre effluent: | |
| Soil erosion (t) | 1.85 |
| Organic N lost to sediment (lbs) | 3.77 |
| NO3 lost to runoff (lbs) | 5.15 |
| NO3 leached beyond root zone (lbs) | 4.47 |
| Phosphorus lost to runoff (lbs) | 0.83 |

---
* Optimal solution calls for 85% of fertilizer "typically" applied.

The 1,000-acre poorly-drained terrace farm demonstrates a considerably different scenario than the well-drained farm. A very small portion of land is used for vegetables (26 acres), while the remainder is used for annual (740 acres) and perennial grass seeds (234 acres) (table IV-9). Few options exist for Dayton soils and most of the (undrained) Amity. As a consequence, the environmental residual associated with this land is nitrates lost to surface runoff. On the vegetable acreage, very high runoff and leaching takes place.

Table IV-9. Optimal solution for unrestricted poorly-drained terrace land farm (1000 acres).

| | |
|---|---|
| Total Farm Profit: | $ 130,112.90 |
| Per Acre | 130.11 |
| Crop rotations (by soil class): | Acres: |
| (Amity) | |
| Perennial ryegrass seed | 200.0 |
| Tall fescue seed | 34.0 |
| Corn/beans | 26.0 |
| (Dayton) | |
| Annual ryegrass seed | 740.0 |
| Per acre effluent: | |
| Soil erosion (t) | 0.14 |
| Organic N lost to sediment (lbs) | 0.72 |
| NO3 lost to runoff (lbs) | 12.23 |
| NO3 leached beyond root zone (lbs) | 3.31 |
| Phosphorus lost to runoff (lbs) | 0.91 |

Although the foothill farm is not intensively tilled (table IV-10), highly profitable land uses predominate: Christmas trees are grown on the steepest slopes, and wheat-annual ryegrass seed on the shallower. Perennial ryegrass seed occupy the remaining acreage. As a consequence of the well-drained nature of Jory soils, considerable leaching of nitrates occurs, in excess of 26 pounds per acre. Erosion rates are generally low (1.8 tons per acre on the wheat-grass fields), but runoff of nitrates and N lost to sediment amount to nearly 9.5 pounds per acre.

In summary, the initial case of unrestricted farm production results in two farms facing groundwater problems, two facing surface runoff problems, and one having a mix of both. Erosion exceeds two tons per acre only on a relatively few acres of two of the farms. Phosphorus runoff was minor in nearly all rotations, and measures aimed at reducing P runoff were not tested. Figure IV-1 summarizes the relative severity of nitrogen and nitrate effluent from the five farms.

Table IV-10. Optimal solution for unrestricted well-drained foothill farm (400 acres).

| | |
|---|---|
| Total Farm Profit: | $ 70,241.44 |
| Per Acre | 175.60 |
| Crop rotations (by slope class): | Acres: |
| ( 5%) | |
| Wheat/annual ryegrass seed (no-till) | 180.0 |
| Perennial ryegrass seed (no fall N) | 13.0 |
| (10%) | |
| Perennial ryegrass seed (no fall N) | 67.0 |
| Christmas trees | 61.0 |
| (15%) | |
| Christmas trees | 79.0 |
| Per acre effluent: | |
| Soil erosion (t) | 1.10 |
| Organic N lost to sediment (lbs) | 5.65 |
| NO3 lost to runoff (lbs) | 3.81 |
| NO3 leached beyond root zone (lbs) | 26.79 |
| Phosphorus lost to runoff (lbs) | 0.00 |

**C. Results of environmental measures on farm-level behavior.**

The results from the EPIC model and the unrestricted ("current scenario") optimization demonstrate the differences in effluent magnitudes across farm types. As a consequence, policy (control) options and responses by farmers to such abatement measures are also likely to vary considerably by farm type. In this section farm-level

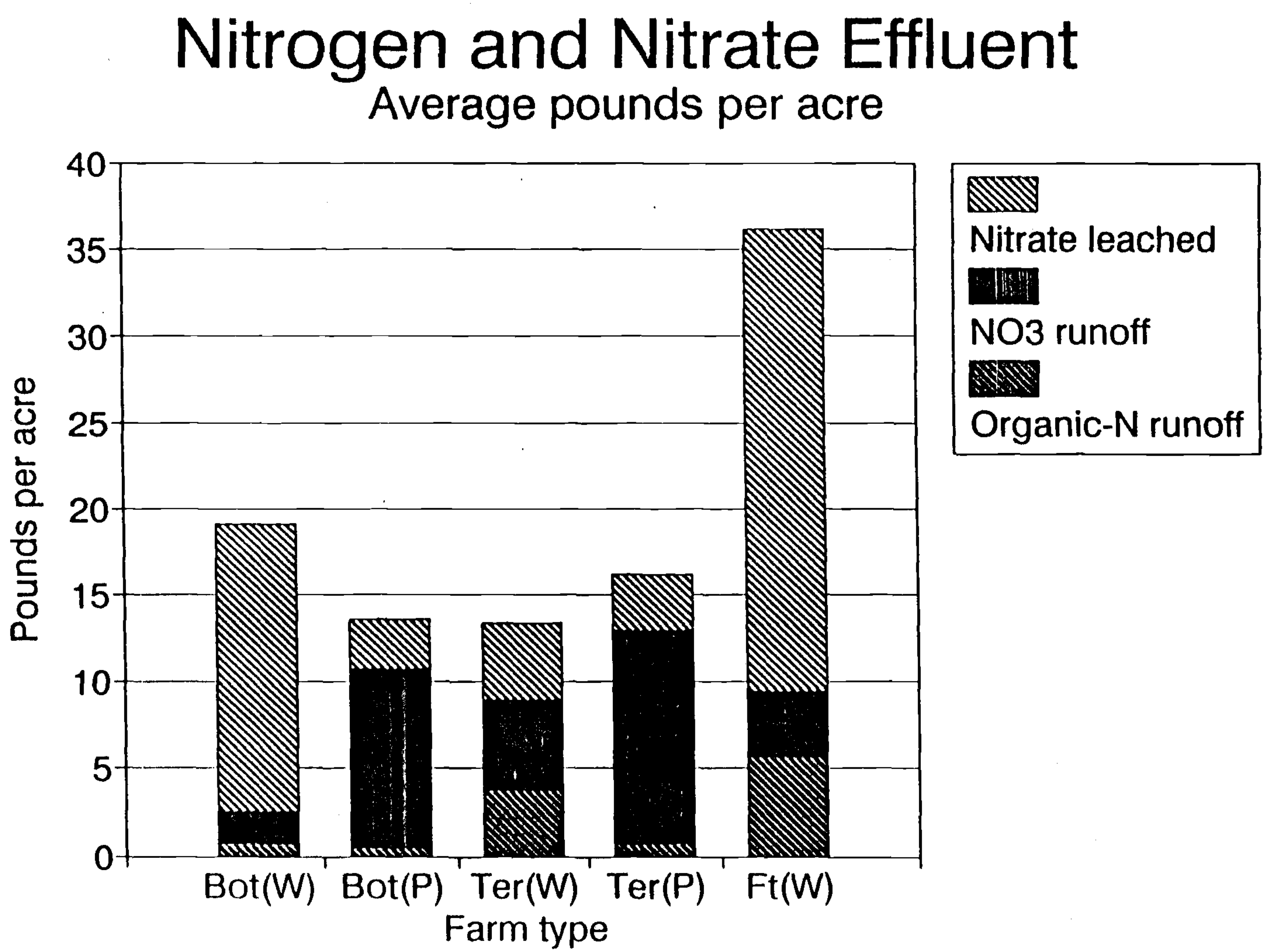



Figure IV-1. Nitrogen and nitrate effluent for unrestricted models.

Responses are discussed in terms of farmer preference (as measured by a change in profit) and comparisons with efficient (or least-cost solutions). Least-cost results are determined by establishing an "efficiency frontier" of LP solutions over the range of abatement levels.

It should be noted that "who pays" is an important factor in divergences between farmer preference (for control options) from control measures having lowest social cost. This occurs for those measures requiring taxes to be collected from farmers, the revenues of which offset (at least partially) the damage losses to society.

*C.1 Well-drained bottomland.*

These soils are some of the most highly productive in the valley, but they are also subject to considerable nitrate leaching. Very little erosion or runoff occurs[6], and subsequently the farm is not responsive to charges or standards aimed at these problem areas. However, when measures are established to affect groundwater leachate rates, changes in the cropping behavior are found.

Table IV-11 (and figure IV-2) contains the results of the LP model, including optimal solutions for a set of leaching abatement levels and the imposition of measures for controlling nitrate leaching. (Actual crop rotations and

---

[6] Bottomland soils are subject to periodic winter flooding during high rainfall periods, a condition which cannot be modeled using EPIC. Therefore, actual mean runoff of nutrients is expected to be larger than predicted here.

Table IV-11. Optimal solutions and measures to induce change in groundwater percolation of nitrates (Well-drained bottomland farm).

| Rank | Policy | Profit (per acre) Total ($) | Profit (per acre) Change ($) | NO3-Leach/Ac Total (lbs) | NO3-Leach/Ac Change (%) |
|---|---|---|---|---|---|
| OPTIMAL SOLUTIONS*: | | | | | |
| | Unrestricted | 147.33 | -- | 16.6 | -- |
| | Ave. $NO_3$ Leached < 15 lb. | 143.57 | - 3.76 | 15.0 | - 9.9% |
| | Ave. $NO_3$ Leached < 12.5 lb. | 135.99 | -11.33 | 12.5 | -24.9% |
| | Ave. $NO_3$ Leached < 10 lb. | 126.62 | -20.70 | 10.0 | -39.9% |
| | Ave. $NO_3$ Leached < 7.5 lb. | 117.21 | -30.12 | 7.5 | -54.9% |
| | Ave. $NO_3$ Leached < 5 lb. | 106.41 | -40.92 | 5.0 | -70.0% |
| | Ave. $NO_3$ Leached < 2.5 lb. | 95.61 | -51.72 | 2.5 | -85.0% |
| | Ave. $NO_3$ Leached < 1 lb. | 88.65 | -58.68 | 1.0 | -94.0% |
| CHARGES ON LEACHATE: | | | | | |
| | $ 4 / lb. Leached | 87.23 | -60.10 | 7.6 | -54.5% |
| | $ 6 / lb. Leached | 82.75 | -64.58 | 0.9 | -94.8% |
| | $ 12/ lb. Leached | 77.93 | -69.40 | 0.7 | -95.9% |
| NITROGEN TAX: | | | | | |
| | + 50% tax on N fertilizer | 122.05 | -25.28 | 16.4 | - 1.7% |
| PER-ACRE STANDARDS: | | | | | |
| | Leached $NO_3$ < 30 lb./ac. | 140.18 | - 7.15 | 16.3 | - 2.3% |
| | Leached $NO_3$ < 20 lb./ac. | 133.56 | -13.77 | 12.8 | -23.0% |
| | Leached $NO_3$ < 15 lb./ac. | 110.85 | -36.47 | 9.8 | -41.1% |
| | Leached $NO_3$ < 10 lb./ac. | 90.60 | -56.73 | 1.6 | -90.5% |
| | Leached $NO_3$ < 6 lb./ac. | 88.48 | -58.85 | 0.8 | -94.2% |
| CONTROLS: | | | | | |
| | Required no-tillage | 144.87 | - 2.46 | 20.8 | +25.0% |
| | Fall fertilizer ban | 137.03 | -10.30 | 18.5 | +10.8% |

* Least-cost solution for average leachate per acre.

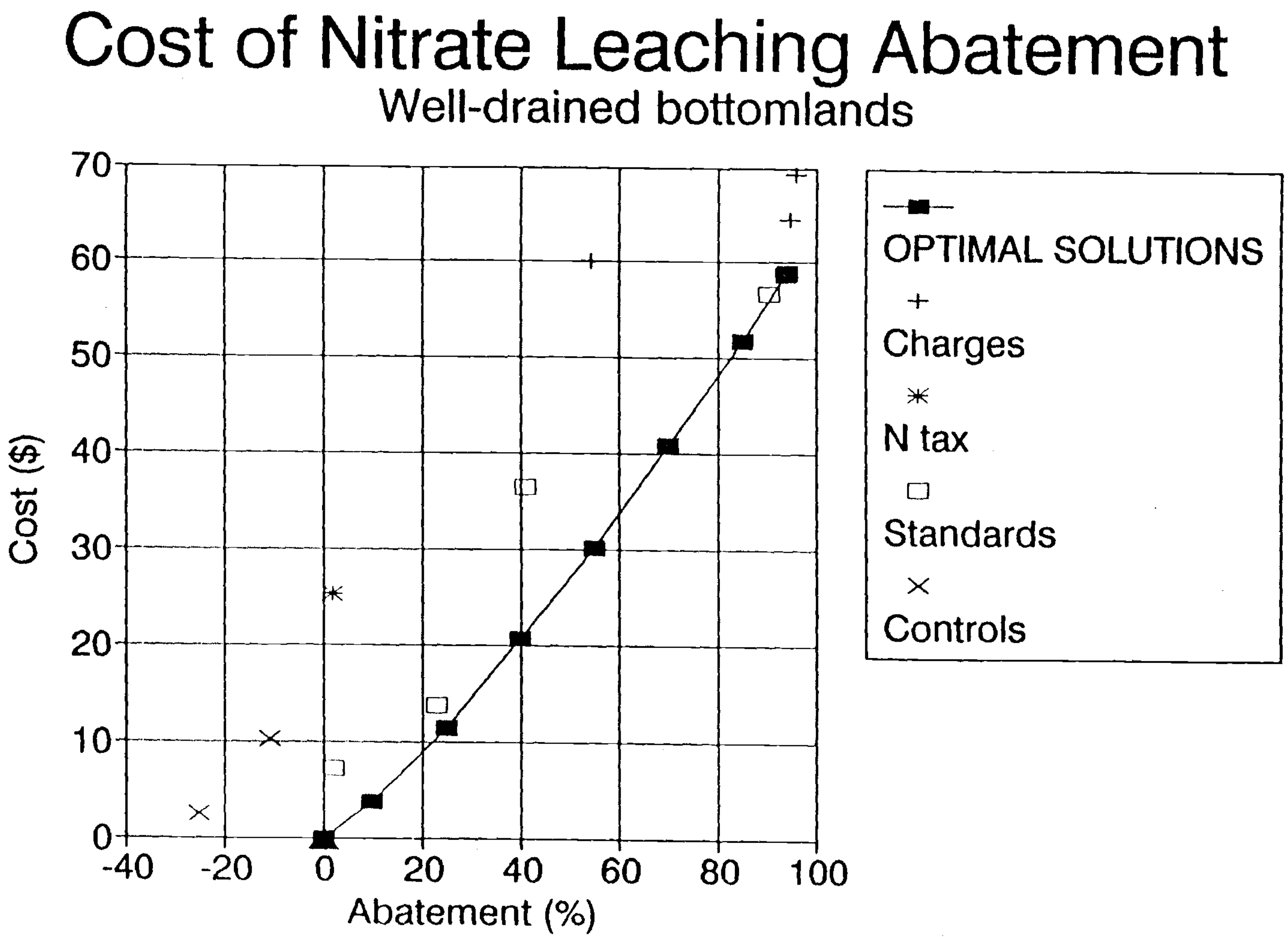



Figure IV-2. Costs of abatement for alternative policies (Well-drained bottomlands).

tillage practices for each solution is included in the appendix.) Only those charge levels and per-acre standards that induce a change are included.

As expected, the "least-cost" crop mixes change in response to various levels of abatement of leachate. (Abatement is accomplished by constraining the farm as a whole to a leachate limit of a specified average per-acre level.) In general, the farm shifts away from monocropping, to greater use of intensive rotations, and to reduced nitrogen applications.

Charges on groundwater leachate induce "nitrogen-conserving" behavior with the LP model. At an effluent tax of $4 per pound of leached nitrates, shifts in crop rotations occur, to 182 acres (from 89 acres) of corn/bean/wheat (with winter clover cover) and 75% fertilizer application, a smaller corn/bean acreage (106 acres from 167 acres), and no-fall-fertilized wheat on 19 acres. At $6 per pound the corn/bean/wheat acreage increases to 297 acres, and nearly 95% of the original leachate is eliminated.

These changes in crop mix come at some cost to farmers, both in terms of the lower absolute profit associated with the new set of crops, and in the tax charge on remaining leachate. But, importantly, the crop mix that results from the charge is consistent with the least-cost solutions. In fact, the differences in profit between the charge and the least cost solution (of the particular abatement level) is just the tax charge for the remaining effluent.

When per-acre standards are imposed, the cost to farmers of achieving similar levels of abatement as in the least-cost solutions is higher, particularly in the mid-range of abatement (for example, at 41.1%). The resulting crop mixes are also considerably different from the least-cost solutions. In general, the solutions achieved for per-acre standards contain crops which are nearly uniform in leachate, tending to have levels close to the specified standard for all acres. This contrasts with the least-cost solution sets, which contain rotations that are high in leachate as well as some that are low. The difference in profit is the additional efficiency loss from the standards. At the highest abatement levels (95%), the profits and rotation mixes are similar, reflecting the limited range of choices at that level of control.

Required use of no-tillage and a fall fertilizer ban are both counter-productive to the objective of decreasing groundwater leachate, as they increase total effluent on the farm while decreasing profit.

*C.2 Poorly-drained bottomland.*

The other riverbottom farm provides the fewest options of all farms; the soil is best suited to grass seed production. Levels of percolated nitrates and erosion are small, but a runoff of nearly 11 pounds of nitrogen and nitrates from the surface was addressed with the policy measures. Table IV-12 and figure IV-3 demonstrate these results. The optimal and least-cost solution pattern reflects shifts of annual ryegrass production into low-fertilizer annual ryegrass, then to irrigated hay.

Runoff taxes are ineffective on this farm. Only at a charge of $8 per pound is there a change in cropping pattern. Even so, only 12% abatement is achieved. This occurs because of the relative profitability of grass seeds and a lack of production alternatives. A 100% tax on nitrogen fertilizer achieves the same result, i.e., abatement and rotation mix, but at considerably less cost to the farm.

When a per-acre runoff standard is applied, on-farm profits are about the same as with an $8 tax, but surface effluent declines by 50%. This is caused by a shift from fully fertilized ryegrass seed to production using only half the present applied amount of nitrogen. A fall fertilizer ban actually increases runoff due to a complete shift to annual ryegrass production, away from perennial grasses. As a consequence, average leachate declines from nearly 3 pounds to less than 1 pound per acre.

*C.3 Well-drained terraces.*

This farm is in many ways the most difficult to target for effluent reduction because improvement in one environmental residual (leaching, runoff, or erosion) often adversely affects another unless multiple instruments are

Table IV-12. Optimal solutions and measures to induce change in surface runoff of nitrates and organic nitrogen (Poorly-drained bottomland farm).

| Rank Policy | Profit (per acre) Total ($) | Change ($) | N-runoff/Ac Total (lbs) | Change (%) |
|---|---|---|---|---|
| OPTIMAL SOLUTIONS*: | | | | |
| Unrestricted | 124.98 | -- | 10.8 | -- |
| Ave. $NO_3$ Runoff < 10 lb. | 123.15 | - 1.83 | 10.5 | - 2.8% |
| Ave. $NO_3$ Runoff < 7.5 lb. | 96.40 | - 28.57 | 7.9 | -27.1% |
| Ave. $NO_3$ Runoff < 5 lb. | 63.64 | - 61.34 | 5.3 | -50.6% |
| Ave. $NO_3$ Runoff < 2.5 lb. | 30.87 | - 94.10 | 2.8 | -74.2% |
| Ave. $NO_3$ Runoff < 1.5 lb. | 17.76 | -107.21 | 1.8 | -83.6% |
| Ave. $NO_3$ Runoff < 1.25 lb. | 14.49 | -110.49 | 1.5 | -86.0% |
| Ave. $NO_3$ Runoff < 1 lb. | -31.75 | -156.73 | 1.3 | -88.4% |
| CHARGES ON RUNOFF: | | | | |
| $ 8 / lb. Runoff | 41.14 | - 83.84 | 9.5 | -12.3% |
| INPUT TAX: | | | | |
| +100% tax on N fertilizer | 81.41 | - 43.57 | 9.5 | -12.3% |
| PER-ACRE STANDARDS: | | | | |
| $NO_3$ + Org-N Runoff < 10 lb. | 43.07 | - 81.91 | 5.8 | -45.9% |
| $NO_3$ + Org-N Runoff < 5 lb. | 13.50 | -111.47 | 1.4 | -86.7% |
| CONTROLS: | | | | |
| Required no-tillage | 124.98 | 0.00 | 10.8 | 0.0% |
| Fall fertilizer ban | 85.79 | - 39.19 | 13.0 | +19.9% |

* Least-cost solution for average leachate per acre.

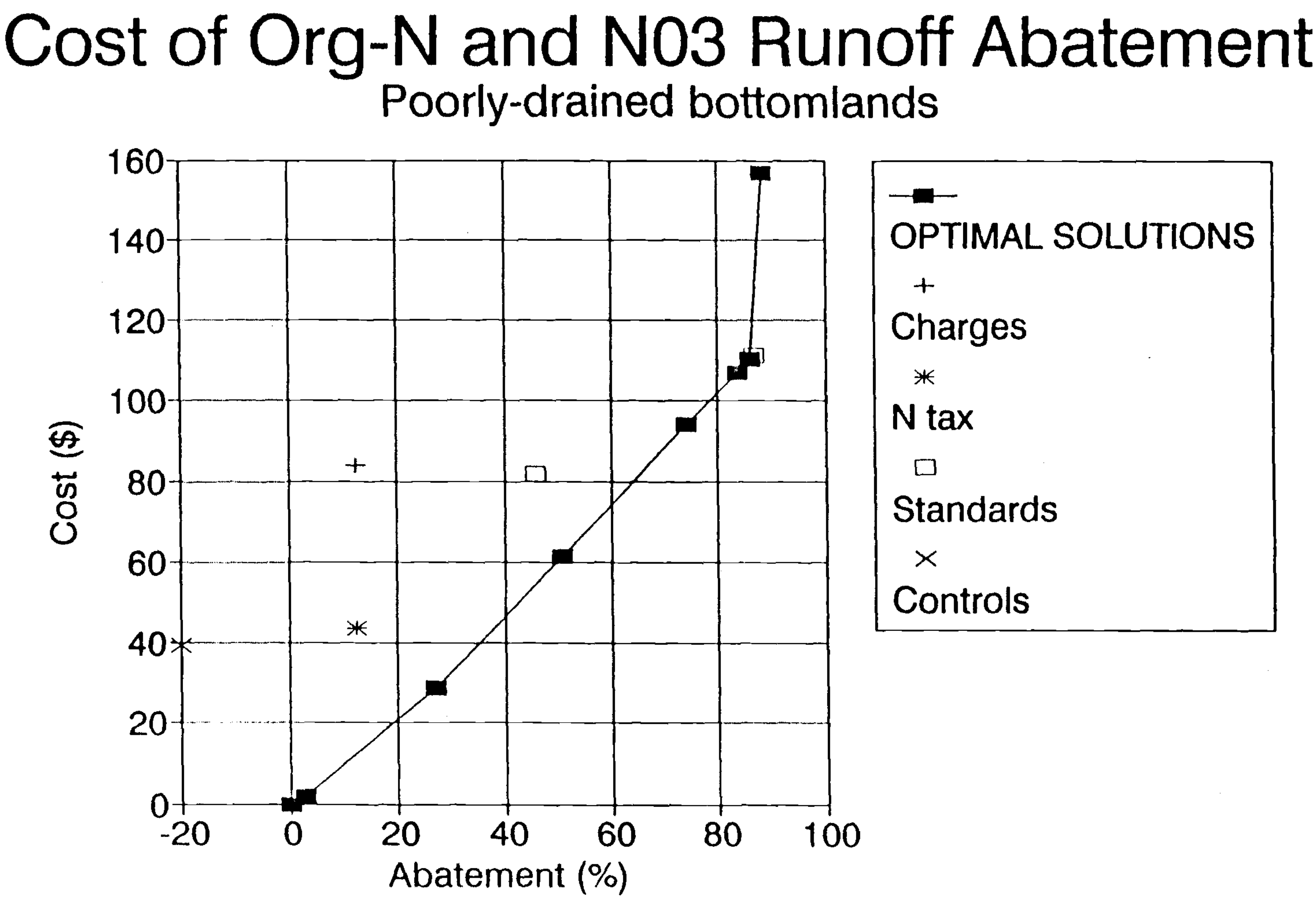



Figure IV-3. Costs of abatement for alternative policies (Poorly-drained bottomlands).

used. At the same time it presents to farmers the widest choice of production options of any farm. Because of the multiple pollution problems there is no single optimal solution path[7], so the rule employed here focused on controlling runoff and leaching in tandem at increasingly restrictive levels. In general, the optimal solution patterns tended to involve more intensive vegetable rotations and longer rotations of perennial crops. One important note is that overall abatement is more difficult on this farm than on the others, due in part to the multiple effluent problem. Even after a $90 per acre decline in profit, only 53% abatement is attained.

In this case Pigouvian taxes are generally ineffective at reducing runoff and leaching, except at the expense of the other (table IV-13 and figure IV-4). When administered together a high charge is encountered. Erosion taxes, however, are able to induce a shift of 80 acres of corn/bean rotation on 6% slope land to 1%, thus curtailing the most serious erosion problem.

The imposition of standards on surface runoff and erosion results in the same crop mix as the erosion tax, but with a slightly higher profit (because no tax revenue is collected). The required use of no-tillage reduced erosion by placing 109 acres into annual no-till wheat (and out of wheat/annual ryegrass seed), but had mixed results on

[7] Optimal control methods are necessary to find the least cost path in order to account for the interactive effects of the pollutants.

Table IV-13. Optimal solutions and measures to induce change in total effluent of surface runoff of nitrates and organic nitrogen, and groundwater percolation of nitrates (Well-drained terrace farm).

| Rank Policy | Profit (per acre) Total ($) | Change ($) | N Runoff Total (lbs) | Change (%) | Leachate Total (lbs) | Change (%) | All effluent Total (lbs) | Change (%) |
|---|---|---|---|---|---|---|---|---|
| OPTIMAL SOLUTIONS*: | | | | | | | | |
| Unrestricted | 142.71 | -- | 8.9 | -- | 4.5 | -- | 13.4 | -- |
| Averages < 7.5 / 5 / 5# | 142.36 | - 0.35 | 6.8 | -23.6% | 4.6 | + 2.2% | 11.4 | -14.5% |
| Averages < 4 / 4 / 4 | 129.76 | - 12.95 | 5.9 | -33.7% | 4.0 | -11.1% | 9.9 | -26.4% |
| Averages < 5 / 3 / 3 | 115.97 | - 26.74 | 4.7 | -47.2% | 3.0 | -33.3% | 7.7 | -28.6% |
| Averages < 3 / 3 / 3 | 91.24 | - 51.47 | 5.4 | -39.3% | 3.0 | -33.3% | 8.4 | -37.5% |
| Averages < 3 / 2 / 2 | 53.25 | - 89.46 | 3.4 | -61.8% | 3.0 | -33.3% | 6.4 | -52.5% |
| CHARGES ON RUNOFF: | | | | | | | | |
| $ 1 / lb. Runoff | 135.55 | - 7.16 | 6.8 | -23.6% | 4.6 | + 2.2% | 11.4 | -14.5% |
| $ 8 / lb. Runoff | 88.39 | - 54.31 | 6.6 | -25.8% | 4.8 | + 6.7% | 11.4 | -14.9% |
| $12 / lb. Runoff | 62.55 | - 80.16 | 6.2 | -30.3% | 5.0 | +11.1% | 11.2 | -16.0% |
| CHARGES ON LEACHATE: | | | | | | | | |
| $ 4 / lb. Leached | 125.30 | - 17.41 | 8.8 | - 1.1% | 3.7 | -17.8% | 12.5 | - 6.7% |
| $12 / lb. Leached | 102.08 | - 40.63 | 10.4 | +16.9% | 1.9 | -57.8% | 12.3 | - 7.7% |
| CHARGES ON RUNOFF AND LEACHATE: | | | | | | | | |
| $ 1 / lb. Runoff & Leached | 130.94 | - 11.77 | 6.8 | -23.6% | 4.6 | + 2.2% | 11.4 | -14.5% |
| $ 4 / lb. Runoff & Leached | 97.57 | - 45.14 | 6.7 | -24.7% | 3.8 | -15.6% | 10.5 | -21.7% |
| $ 8 / lb. Runoff & Leached | 56.18 | - 86.53 | 6.6 | -25.8% | 2.6 | -42.2% | 9.2 | -31.5% |
| $12 / lb. Runoff & Leached | 20.92 | -121.79 | 6.5 | -27.0% | 1.2 | -73.3% | 7.7 | -42.3% |
| CHARGES ON EROSION: | | | | | | | | |
| $ 2.50 / ton eroded | 140.80 | - 1.91 | 6.8 | -23.6% | 4.6 | + 2.2% | 11.4 | -14.5% |
| INPUT TAX: | | | | | | | | |
| + 50% on N fertilizer | 118.78 | - 23.93 | 8.9 | 0.0% | 4.4 | - 2.2% | 13.3 | - 1.2% |
| +100% on N fertilizer | 97.01 | - 45.70 | 8.9 | 0.0% | 4.2 | - 6.7% | 13.1 | - 2.6% |
| PER-ACRE STANDARDS: | | | | | | | | |
| Leached $NO_3$ < 5 lb./ac. | 122.14 | - 20.57 | 8.1 | - 9.0% | 3.9 | -13.3% | 12.0 | -10.6% |
| $NO_3$ + Org-N < 20 lb./ac. | 142.38 | - 0.33 | 6.8 | -23.6% | 4.6 | + 2.2% | 11.4 | -14.5% |
| $NO_3$ + Org-N < 5 lb./ac. | 3.23 | -139.48 | 1.5 | -83.1% | 3.9 | -13.3% | 5.4 | -59.7% |
| Erosion < 5 tons | 142.38 | - 0.33 | 6.8 | -23.6% | 4.6 | + 2.2% | 11.4 | -14.5% |
| Leached $NO_3$ < 5 lb./ac. & Erosion < 5 tons | 119.70 | - 23.01 | 6.4 | -28.1% | 3.2 | -28.9% | 9.6 | -28.4% |
| CONTROLS: | | | | | | | | |
| Required no-tillage | 133.60 | - 9.11 | 8.5 | - 4.5% | 5.5 | +22.2% | 14.0 | + 4.6% |
| Fall fertilizer ban | 121.34 | - 21.37 | 9.4 | + 5.6% | 4.7 | + 4.4% | 14.1 | + 5.4% |

* Values indicate limits on leachate, $NO_3$ runoff, and Organic-N runoff, respectively, in average pounds per acre.

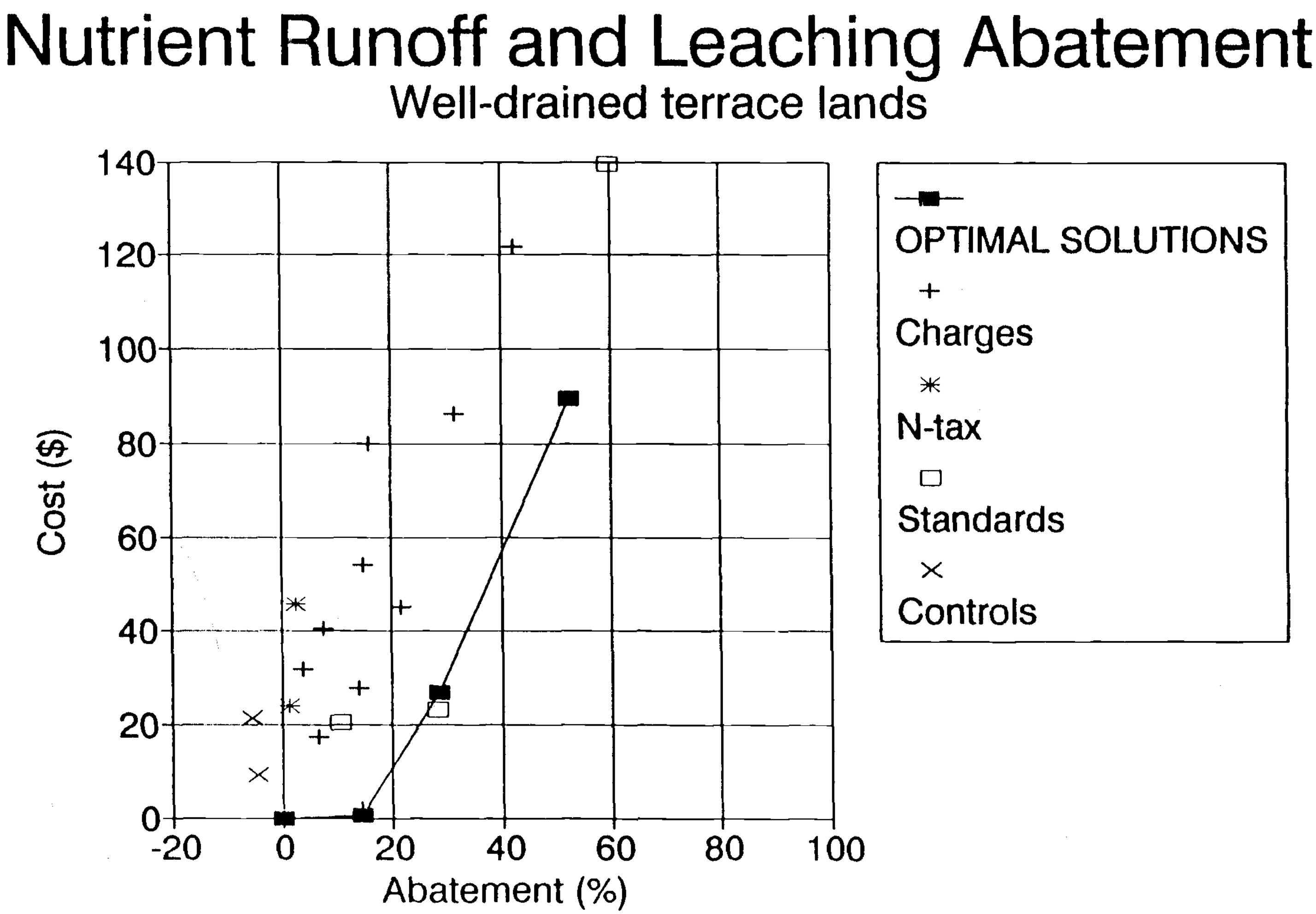



Figure IV-4. Costs of abatement for alternative policies
(Well-drained terraces).

surface runoff and leaching rates. Nitrogen input taxes only slightly decrease effluent, but reduce profits considerably.

*C.4 Poorly-drained terraces.*

Nearly all acreage in this large farm is in grass seed rotations, and surface runoff of nitrates is the greatest concern. (A small percentage of intensive vegetable crops does have high leachate levels.) However, due to limited cropping and management options, significant reduction of effluent comes only at high cost (table IV-14 and figure IV-5). The farm encompasses two soils, and the pattern of optimal solutions are different. On Amity soils, perennial ryegrass and tall fescue shift to a perennial grass and wheat rotation, and on Dayton soils no-till is replaced by mold-board plow and then by pasture. (The shift to mold-board plow reflects its lower estimated nitrogen runoff.)

The dichotomy of choices (profitable grass seeds versus less-profitable pasture) is evident in the response to charges on runoff, and runoff and leachate. Only at high charge levels is significant abatement achieved, and then at a high cost. Input taxes also have a minor effect on runoff (less than 10%).

Restrictive per-acre standards on runoff are able to achieve an intermediate abatement level (50%) unattainable by charges, but again, the crop mix is considerably different than the comparable optimal solution mix. An

Table IV-14. Optimal solutions and measures to induce change in surface runoff of nitrates and organic nitrogen (Poorly-drained terrace farm).

| Rank Policy | Profit (per acre) Total ($) | Profit (per acre) Change ($) | N-runoff/Ac Total (lbs) | N-runoff/Ac Change (%) |
|---|---|---|---|---|
| OPTIMAL SOLUTIONS*: | | | | |
| Unrestricted | 130.11 | -- | 13.0 | -- |
| Ave. $NO_3$ Runoff < 10 lb. | 122.04 | - 8.07 | 10.7 | -17.5% |
| Ave. $NO_3$ Runoff < 7.5 lb. | 96.75 | - 33.36 | 8.1 | -37.8% |
| Ave. $NO_3$ Runoff < 5 lb. | 71.30 | - 58.81 | 5.4 | -58.0% |
| Ave. $NO_3$ Runoff < 2.5 lb. | 45.55 | - 84.56 | 2.8 | -78.2% |
| Ave. $NO_3$ Runoff < 1.75 lb. | 15.91 | -114.20 | 0.9 | -85.1% |
| CHARGES ON RUNOFF: | | | | |
| $ 2 / lb. Runoff | 104.86 | - 25.26 | 11.9 | - 8.6% |
| $ 6 / lb. Runoff | 58.64 | - 71.48 | 11.0 | -15.4% |
| $12 / lb. Runoff | 12.67 | -117.45 | 2.3 | -82.0% |
| CHARGES ON RUNOFF AND LEACHATE: | | | | |
| $ 1 / lb. Runoff & Leached | 114.26 | - 15.86 | 12.8 | - 1.1% |
| $ 2 / lb. Runoff & Leached | 99.08 | - 31.03 | 11.8 | - 8.9% |
| $12 / lb. Runoff & Leached | -13.52 | -143.63 | 2.3 | -82.5% |
| INPUT TAX: | | | | |
| + 50% tax on N fertilizer | 106.89 | - 23.22 | 12.6 | - 2.9% |
| +100% tax on N fertilizer | 86.73 | - 43.39 | 11.8 | - 8.9% |
| PER-ACRE STANDARDS: | | | | |
| Leached $NO_3$ < 15 lb./ac. | 129.78 | - 0.33 | 12.8 | - 1.1% |
| $NO_3$ + Org-N < 10 lb./ac. | 46.72 | - 83.39 | 6.4 | -50.5% |
| $NO_3$ + Org-N < 5 lb./ac. | 10.37 | -119.74 | 2.0 | -84.4% |
| CONTROLS: | | | | |
| Required no-tillage | 130.11 | 0.00 | 13.0 | 0.0% |
| Fall fertilizer ban | 114.66 | - 15.45 | 12.7 | - 1.8% |

* Least-cost solution for <u>average</u> leachate per acre.

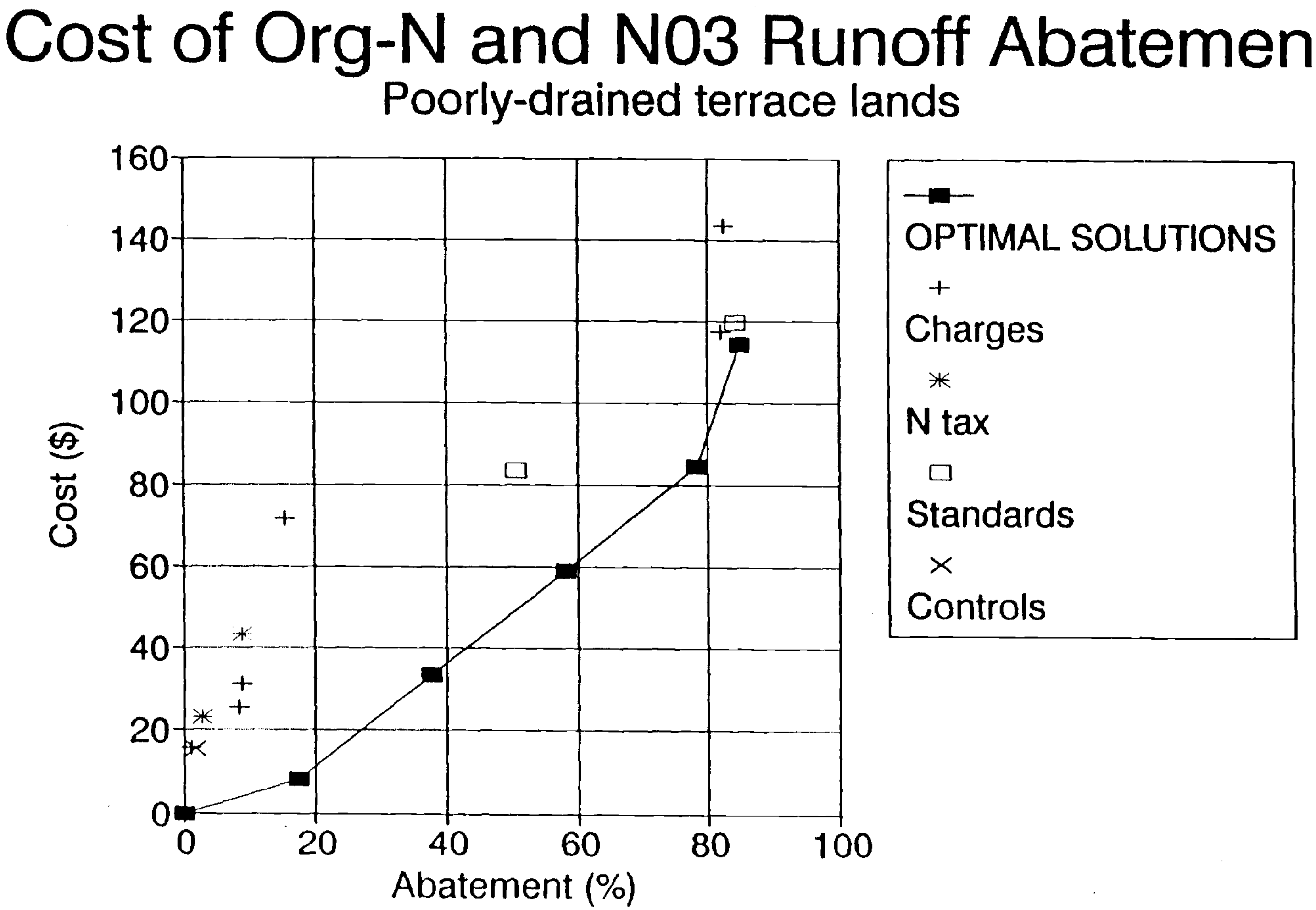



Figure IV-5. Costs of abatement for alternative policies (Poorly-drained terraces).

unusual blend of rotations with 50% nitrogen applied, and others with full nitrogen is the result.

The required use of no-till has no effect on profits or effluent, as it is already the most profitable means of production for grass seed. A fall fertilizer ban has a minor impact on runoff at a cost of 12% in profits.

*C.5 Well-drained foothills.*

These soils are subject to erosion problems (under intense cultivation) and severe leaching of nitrates. Controls therefore should be primarily aimed at reducing groundwater contamination, but the results show that only a limited reduction is possible without very high costs (table IV-15 and figure IV-6). A point of interest, however, is that the most profitable crops for the foothills tend to be those with good erosion control characteristics, such as grass seed and Christmas trees with groundcover. The pattern of the optimal solutions is one in which the cultivated acreage (at the 5% slope) tend to be replaced by Christmas trees, then revert back to rangeland.

Charges for leached nitrates and nutrient runoff do reduce effluent, and tend to cause the steepest slopes (15%) to be used for rangeland or Christmas trees. Per-acre standards (on leaching and on runoff) result in effective control of 43% of total effluent for about a 20% loss in profit. Beyond this, however, further reductions come only at very high cost. Most of the shifts in production involve

Table IV-15. Optimal solutions and measures to induce change in total effluent of surface runoff of nitrates and organic nitrogen, and groundwater percolation of nitrates (Well-drained foothill farm).

| Rank Policy | Profit (per acre) Total ($) | Profit (per acre) Change ($) | N Runoff Total (lbs) | N Runoff Change (%) | Leachate Total (lbs) | Leachate Change (%) | All effluent Total (lbs) | All effluent Change (%) |
|---|---|---|---|---|---|---|---|---|
| OPTIMAL SOLUTIONS*: | | | | | | | | |
| Unrestricted | 175.60 | -- | 9.5 | -- | 26.8 | -- | 36.3 | -- |
| Average < 20 / 7.5 / 7.5 | 163.94 | - 11.67 | 7.5 | -21.1% | 20.0 | -25.4% | 27.5 | -24.1% |
| Average < 17.5 / 5 / 5 | 154.87 | - 20.73 | 5.2 | -45.3% | 17.5 | -34.7% | 22.7 | -37.5% |
| Average < 15 / 5 / 5 | 145.91 | - 29.69 | 4.0 | -57.9% | 15.0 | -44.0% | 19.0 | -47.5% |
| Average < 12.5 / 5 / 5 | 134.83 | - 40.77 | 3.4 | -64.2% | 12.5 | -53.3% | 15.9 | -56.1% |
| Average < 10 / 5 / 5 | 81.83 | - 93.77 | 3.0 | -68.4% | 10.0 | -62.7% | 13.0 | -64.2% |
| Average < 7.5 / 3 / 3 | 28.66 | -146.94 | 2.8 | -70.5% | 7.5 | -72.0% | 10.3 | -71.5% |
| CHARGES ON RUNOFF: | | | | | | | | |
| $ 2 / lb. Runoff | 157.87 | - 17.73 | 8.1 | -14.7% | 22.9 | -14.6% | 31.0 | -14.3% |
| $ 6 / lb. Runoff | 125.48 | - 50.12 | 7.8 | -17.9% | 22.8 | -14.9% | 30.6 | -15.6% |
| $ 8 / lb. Runoff | 115.30 | - 60.31 | 3.0 | -68.4% | 13.7 | -48.9% | 16.7 | -54.0% |
| CHARGES ON LEACHATE: | | | | | | | | |
| $ 1 / lb. Leached | 151.19 | - 24.41 | 8.1 | -14.7% | 22.9 | -14.6% | 31.0 | -14.3% |
| $ 4 / lb. Leached | 86.90 | - 88.70 | 2.9 | -69.5% | 12.6 | -53.0% | 15.5 | -57.2% |
| CHARGES ON RUNOFF AND LEACHATE: | | | | | | | | |
| $ 1 / lb. Runoff & Leached | 143.06 | - 32.54 | 8.1 | -14.7% | 22.9 | -14.6% | 31.0 | -14.3% |
| $ 4 / lb. Runoff & Leached | 75.38 | -100.22 | 2.9 | -69.5% | 12.6 | -53.0% | 15.5 | -57.2% |
| INPUT TAX: | | | | | | | | |
| + 50% tax on N fertilizer | 159.18 | - 16.42 | 8.1 | -14.7% | 22.9 | -14.6% | 31.0 | -14.3% |
| PER-ACRE STANDARDS: | | | | | | | | |
| Leachate < 30 lb./ac. | 140.10 | - 35.50 | 4.2 | -55.8% | 16.2 | -39.6% | 20.4 | -43.6% |
| Leachate < 20 lb./ac. | 7.83 | -167.77 | 3.0 | -68.4% | 8.1 | -69.8% | 11.1 | -69.4% |
| Leachate < 10 lb./ac. | 5.13 | -170.48 | 2.8 | -70.5% | 6.4 | -76.1% | 9.2 | -74.6% |
| $NO_3$ + Org-N < 10 lb./ac. | 140.10 | - 35.50 | 4.2 | -55.8% | 16.2 | -39.6% | 20.4 | -43.6% |
| CONTROLS: | | | | | | | | |
| Required no-tillage | 164.96 | - 10.64 | 7.8 | -17.9% | 31.0 | +15.7% | 38.8 | + 7.0% |
| Fall fertilizer ban | 137.40 | - 38.20 | 2.9 | -69.5% | 12.6 | -53.0% | 15.5 | -57.1% |

* Least-cost solution for <u>average</u> leachate per acre.

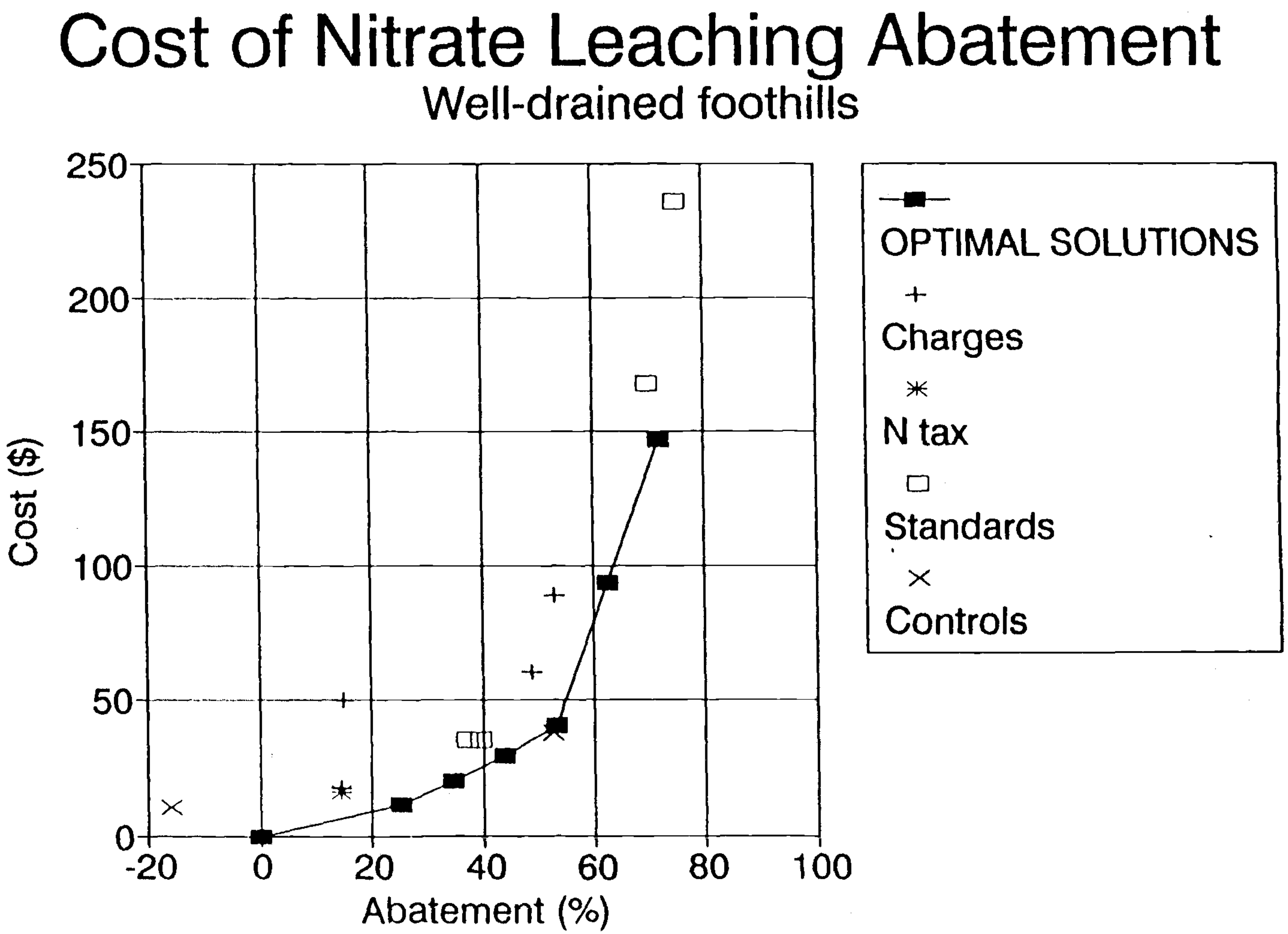



Figure IV-6. Costs of abatement for alternative policies (Well-drained foothills).

moving the highly profitable perennial grass seeds to the lower slopes, and replacing large segments of land with unimproved range.

Required use of no-till reduces erosion and subsequent nutrient runoff, but increases the level of groundwater leaching. As in other soils, this limits production options, including the wheat/grass seed rotations in favor of continuous no-till wheat. A fall ban on fertilizer application is very effective at reducing leaching, as well as in controlling erosion and runoff.

**D. Effectiveness of pollution control measures.**

The results from the five representative farms suggest that the effectiveness of each pollution control measure varies among farms. Important factors which influence this effectiveness include the range of production and cropping options available to farmers, and their relative profitability.

Charges result in crop mixes similar or identical to the least cost "optimal solutions" for the range of abatement levels, on the better drained soils. While no particular abatement level can be targeted with charges, those solutions that result from charges are consistent with the least-cost solution.

However, charges are relatively ineffective at inducing farmers on more poorly drained soils to change production behavior; instead, crop mixes remain similar to the unrestricted case, and the tax is merely absorbed. This reflects the dichotomy of options facing these particular farms: more profitable grass seeds versus less profitable hay and pasture are the extent of options available. There is a greater willingness to absorb high levels of taxes (after minor adjustments in production methods) before switching to hay and pasture.

The input tax on nitrogen reduces N applications on all farms; but at the levels tested (50% and 100%) overall abatement was relatively small. This is a reflection of the high marginal value of nitrogen for most crops. Differences in effectiveness between farms reflects, in part, the differences in utilization rates of nitrogen between crops.

Per-acre standards result in highly divergent crop mixes over the range of abatement, but converging in the low and high abatement ranges, as compared to crop mixes which result from the "least-cost solutions." The difference is that all acres in the farm tend to be more uniformly polluting under standards, rather than a mix of higher and lower polluting rotations found in the optimal solution cases. This condition occurs most (and results in largest additional cost) in the middle ranges of abatement. At lower levels the standards are less limiting and the "best" rotations tend to be selected, while at higher abatement fewer options are available in the optimal solution and standards cases.

Direct controls are of limited value in the Willamette

Valley. A "fall fertilizer ban" results in a crop mix comparable to an optimal solution only on the foothill farm. It also generates some abatement on the poorer drained soils. But a ban has a negative effect on pollution abatement on the better drained soils, as it induces shifts away from fall seeded crops and towards (higher polluting) vegetable production. A requirement to use no-till on small grains and grass seeds is also generally not applicable to the valley due to its tendencies to increase groundwater leaching of nitrates. No-till is effective at controlling erosion, but that is not a significant problem in the Willamette Valley.

**E. Implications of results and recommendations.**

The results for the five representative farms provide varying and sometimes contradictory implications; however, a number of insights can be gleaned. These conclusions are discussed in this section, followed by recommendations for policy makers.

*E.1 Implications of results.*

1. Optimal solution results for each farm indicate that some abatement of pollution is possible on all farms for relatively little cost. This point is demonstrated in table IV-16. In general, a slight change in operations or application rates of nitrogen is sufficient to attain 5% to

24% abatement, depending upon the pollutant and the farm type. Even this abatement level is more expensive for the more poorly drained land.

Table IV-16. Cost per acre of attaining nitrogen and nitrate abatement for five representative farms, Willamette Valley.

| FARM | COST* | ABATEMENT | TARGET | COST PER POUND# |
|---|---|---|---|---|
| Well-drained bottomland | $ 3.76 | 9.9% | Ground | $2.29 |
| Poorly-drained bottomland | 1.83 | 4.7% | Surface | 6.10 |
| Well-drained terraces | 0.35 | 14.5% | Both | 0.18 |
| Poorly-drained terraces | 8.07 | 17.5% | Surface | 3.57 |
| Well-drained foothills | 11.67 | 24.1% | Both | 1.33 |

* Farm cost per acre in terms of reduced profit.
\# Reduced farm profit divided by change in nitrogen effluent, from tables IV-11 to IV-15.

2. Where a charge and standard provide the same level of abatement, the charge net of taxes will provide abatement at least cost. In some cases standards and charges result in the same crop mix, but the mix that results from imposed charges is always consistent with the optimal solution.

3. Charges are effective at inducing efficient behavior with respect to nitrogen, but their effectiveness is more limited on soils with few production options. In particular, very high charge levels (e.g., $12 / lb.) may be necessary on poorly drained soils to achieve significant abatement.

4. On four of the five farms, the focus in which pollution control (surface runoff of nutrients, nitrate leaching to groundwater, or soil erosion) should take is clear. Also, when the pollutant is targeted, the control measure is effective in reducing total effluent from the farm. However, for the well-drained terrace farm, which represents the largest land base in the valley, there is substantial ambiguity as to control strategies. If surface runoff or leaching is targeted for control, the other pollutant may be exacerbated. As a result, high levels of total effluent abatement (above 50%) may be prohibitively expensive.

5. Farmers in the Willamette Valley can reduce both nitrogen fertilizer use and effluent with a greater use of crop rotations, including winter cover crops for vegetables.

*E.2 Recommendations.*

As was demonstrated earlier, nutrient effluent from the representative farms differs both in volume and receiving waters (surface, ground water, or both). This indicates that a single policy, aimed at one type of pollutant and targeted on all farms in the valley, will not substantially reduce agricultural effluent as a whole, and may actually exacerbate other pollution problems. Therefore, abatement policies should address pollutants by soil quality (e.g., drainage potential), by farm type (such as vegetable farms for groundwater leachate), or by geographic location.

Because relatively small changes in practices can achieve some abatement, and these changes provide abatement at least cost, they should be the first to be considered for voluntary or mandatory adoption. They would involve practices which could be considered "Best Management": decreasing nitrogen applications on at least a portion of the farm acreage, moving tillage-intensive crops to lower slopes, or lengthening vegetable crop rotations to include small grains and winter cover crops.

On well-drained farmlands (particularly where many production options exist), effluent charges could be implemented to achieve abatement at least cost, if monitoring were feasible. Though specific abatement levels may be difficult to target, charges still remain more efficient than per-acre standards.

The poorly-drained grass seed farms pose definite abatement difficulties, because of the lack of production alternatives. It must be considered whether the benefits from clean water outweigh the cost of achieving it. On the poorly-drained terrace farms some amount of runoff reduction was estimated by shifting ryegrass seed from no-till to conventional tillage, but additional field tests would be necessary before making this recommendation.

A truly least-cost method of achieving various abatement levels would involve farmers simply adopting the practices and rotations indicated by the least-cost "efficiency frontier" for each farm type. While farmers would absorb the costs through a loss in profit (assuming there are no supply-induced effects on crop prices), voluntary adoption would cost society less than any of the regulatory measures because of implementation and monitoring costs.

# V. SUMMARY AND CONCLUSIONS

The results and implications discussed in Chapter IV are useful for addressing agricultural externalities in the Willamette Valley. It is important as well to consider how the analysis of this problem may be adapted to other settings, and to determine extensions of this research. In this chapter the specific results and conclusions are discussed in terms of its contributions to the understanding of the economic relationships between farming practices and water quality in the Willamette Valley, and for limitations and research needs.

The chapter is divided into three sections. The first section is a summary of the research problem and the physical, institutional, and economic dimensions of agricultural externalities. It also contains a summary of the approach and procedures used here for analysis of pollution control measures, and essential results and implications of the analysis. The next section considers limitations of the study and needs for future research. The final section elaborates on lessons and applications of this research.

## A. Summary

Changes in the structure of the U.S. agricultural industry since World War II, due in part to publically funded research and a range of government programs and policies, have transformed it into a highly productive component of the domestic economy. As a result the agricultural industry provides high levels of output at low consumer prices, and has become an important foundation to America's international trade.

But these changes in agriculture are not without indirect costs. For example, the reliance on agricultural chemicals has produced environmental effects causing growing concern. In addition, renewed awareness of and demand for environmental amenities by the general public are changing attitudes towards the agricultural industry and its implicit property rights. This public concern is prompting a growing use of regulatory controls for pollution problems, at a time of greater demands on water resources and declining farm sector population and political clout. It is therefore important to examine economic incentives and other mechanisms available to farmers to offset pollution, so as to provide insight into the effectiveness of achieving goals of a sustainable food supply while meeting environmental demands in rural areas.

The objectives of this dissertation were to assess farm-level responses to alternative regulatory policies for the control of nutrient flow from farmland, with particular application to the Willamette Valley of Oregon.

In chapter two the physical, institutional, and economic dimensions of agricultural externalities were explored. One of the primary national environmental concerns about agricultural production methods is the effect of agricultural pollution on water quality, and subsequent impacts on human and animal health, wildlife, water treatment costs, and recreational activities. These environmental damages arise from three agricultural processes: (1) soil erosion resulting in sediment deposited off the farm field, (2) fertilizer and pesticide runoff deposited directly in surface water courses, and (3) fertilizer, nutrients and pesticides percolating into groundwater.

In the process of growing crops, loosened topsoil that has moved to a streambed imposes additional costs on other users of that water. Nutrients attached to that sediment and water-soluble chemicals in runoff can also be deposited in waterways. The sediment and nutrients can harm fish and cause turbidity and excessive plant growth, reducing recreational opportunities. Human health may also be affected when surface or groundwater containing nitrates or pesticides is used for consumption.

While there exists a socially optimal level of effluent from agricultural processes, evidence suggests that this level is exceeded in many locations, sometimes by great amounts. Oregon is one of 17 states which identified agriculture as a primary or major nonpoint source of pollution.

Farmers can affect agricultural effluent through management (by choice of crop rotation and mix, sources and application levels of nutrient, and pest control) and tillage practices (conventional tillage, minimum tillage, or no-tillage), particularly by incorporation of "Best Management Practices." The BMP's interrelationship with water quality, and how water quality regulation affects the choice of management or tillage, are becoming important considerations for farmers, conservation agencies, and policy planners.

The existence of agricultural pollution suggests an externality exists in the system, and that the market is not properly allocating clean water. While many agricultural professionals see water quality as an information problem, many non-agriculturalists view public policy and direct controls, or a redefinition of property rights, as the solution.

The problem facing policy makers is how to solve the environmental problems without significantly harming the industry. There are four general approaches in the literature for correcting externalities:

- Charges (or Pigouvian taxes), which involve a direct tax on the effluent causing the externality. It is an appropriate theoretical tool, but it requires considerable information that may be difficult or impossible to find, such as full cost or damage functions, and is difficult to implement.

- Input taxes (such as for nitrogen fertilizer). They are easy to implement, but may not be very effective at reducing effluent if there is a high marginal value or inelastic demand for the input, or when crops have different utilization rates.

- o Standards, defined as levels representing an "acceptable environment," are set subjectively on the basis of scientific evaluation. They may be a least-cost method, but in general are only appropriate when the existing situation imposes a high level of social costs not correctable by other means.
- o Controls, which involve a directive to decision makers about specific practices that must be used (such as no-tillage) or which are banned from use (such as certain pesticides). They are generally inexpensive to implement, but are likely to be more costly to farmers.

Chapter three contains an outline of the approach and procedures used in assessing on-farm pollution control options. The analysis uses a general two-part simulation involving (1) an environmental parameter component and (2) an economic optimization routine. The process centers around the EPIC simulator and the LP representative farm model. EPIC is a biophysical simulator designed to simulate crop growth and nutrient flow under conditions considering climate and soil and farming system characteristics. Among the outputs from EPIC are annual crop yields (averaged over the simulation period) and nutrient flow levels.

A separate linear program for each of the representative farms was used. Farm-level data were used to generate crop budgets, and farm specific behavior (relating to rotations and tillage practice combinations) was used in forming both activities and constraints. Associated nutrient flow levels and yields from EPIC were incorporated as coefficients. Environmental restrictions and regulations were also imposed when conducting policy tests.

The output of each of the farm models is an optimal (profit maximizing) crop mix (including rotation and tillage practices), and an associated set of environmental outflows. The changes in profit, crop mix, and physical outputs recorded between the unrestricted (unregulated) farm and that farm under imposed policies provided a measure of policy effectiveness and cost.

The empirical focus of this study was the Willamette Valley of Oregon. The Willamette Valley represents an important diversified agricultural region in the Pacific Northwest. Important commodities include grass grown for seed, hay for cattle and dairy farms, and small grains; other crops include vegetables for processing, berries and horticultural products. Its climate consists of mild summers and cool, wet winters. The winter precipitation is an important climatic characteristic due to the high proportion of fall seeded crops. In fact, the EPA ranked the Willamette River Basin in the highest category of phosphorus, inorganic nitrogen and total nitrogen levels, relative to other parts of the United States, due in part to these crops. The Willamette Valley also contains nearly 80% of the state's population, creating interesting resource demand problems.

Because the valley is a region with no single crop- or farm-type dominant, five farm-types were defined to represent the major combinations of crops, soil types, and geographic subregion within the valley. These include two farms from the river bottom land, two from the broad terrace land, and one from the foothills. An important characteristic of the farms is the range of options available to farmers of the different types, and how they may respond to imposed inducements.

Five policy options were tested. They included:

* A per-unit tax of levels on leached nitrates, surface runoff of organic nitrogen and nitrates, and both classes combined.
* A tax on nitrogen fertilizer, implemented as a tax of 50% and 100% to the cost of nitrogen.
* Per-acre standards of various levels, imposed by placing a maximum limit on per-acre runoff (or leachate).
* A requirement for use of no-till drills on small grains and grass seed production
* A ban on fertilizer use in autumn months, as a means of reducing leaching in the damp winter months.

The fourth chapter presented the results of EPIC simulator and the LP models for each farm, in unrestricted form and with the pollution control policies imposed. The simulation outputs and unrestricted model results indicated the type and severity of pollution problems for the representative farms, which varied by farm according to physical characteristics of the soils. The focus of pollution control, therefore, differed by farm type.

Comparing "least-cost solutions" with those of the imposed policies provided insights into their relative effectiveness:

* Charges result in crop mixes similar or identical to "least-cost solutions" for the range of abatement levels; however, charges are relatively ineffective on poorly-drained soils because of a lack of production options.

* Input taxes on nitrogen reduces N use on all farms, but with limited abatement potential.

* Per-acre standards result in highly divergent crop mixes over the range of abatement, as compared to the "least-cost solutions." The difference is that all acres tend to be uniformly polluting under standards, rather than "some high, some low" as in the least-cost solution cases.

* Direct controls are of limited usefulness in the valley. A fall fertilizer ban resulted in an "optimal solution" crop mix <u>only</u> on the foothill farm. A no-till requirement is generally not applicable due to higher groundwater leaching.

* Least-cost solution patterns favor more intensive vegetable/ grain or grass seed/wheat rotations, and perennial crops.

Finally, these results have implications for Willamette Valley farmers regarding agricultural pollution:

* Some abatement is possible on all farms for relatively little cost, usually entailing minor changes in practices.

* Where a charge and standard provide the same level of abatement, the charge <u>net of taxes</u> is least cost.

* Control of one type of pollutant may exacerbate other problems when a farm is subject to multiple pollution problems. In such a case, achieving high levels of abatement may be prohibitively expensive.

* Farmers in the Willamette Valley can reduce both nitrogen fertilizer use and effluent with greater use of crop rotations.

**B. Limitations and research needs.**

The modeling process, particularly one involving a number of component parts, necessarily requires simplifying assumptions. In addition, the scope of the study must also be well-defined and narrow in focus, so as to facilitate data gathering and relevant analysis. At the same time, related and peripheral issues important to the understanding of an entire system must be overlooked or not considered.

One concept central to the decision-making process but considered to a limited degree in this study is risk and financial management, which enters the problem in two ways. First is the role of stochastic weather events, and influences on decisions within a cropping season. The nature of the biophysical model requires a non-feedback, non-learning production process, whereby a production plan cannot be adjusted during a season (or rotation). Such an ability would undoubtedly affect crop yields as well as resultant effluent, and a dynamic feedback analysis is worthy of study.

The second aspect of risk revolves around the financial portfolio of farmers and their ability to adjust (instantaneously or over time) to requirements of changes in practices. In particular, the financial well-being of farmers may have an influence both in selection of policy instrument as well as targeted abatement levels.

Another important issue centers on the static versus dynamic aspect of the overall analysis. In this study no consideration is given to a farmer's initial or resulting assets and production plan, or the transition period between this time. In some cases this would have little effect on policy instrument or financial status, but widespread changes in plan and production needs can alter a policy's relative ranking.

The changes in quantity and types of crops grown, and the resulting aggregation, may have significant impacts on local and regional markets, especially for commodities for which the region holds particular dominance (as is the case with grass seeds and Christmas trees in the Willamette Basin). This problem was handled here by placing production limits on relevant commodities (representing contract limitations), but a more sophisticated market analysis (price endogenous) would improve the results for those products.

Finally, there is the issue of an appropriate level of pollution abatement. This study focused on only one side of the (non-) market problem, the supply of "clean water." In order to determine the appropriate target level that pollution control should take requires an analysis of the demand side. A determination of the willingness-to-pay of affected parties for clean(er) water will help establish an optimal abatement level. Establishment of the target level could also have an influence on the choice of control instrument, which may be "locally superior" within a range of abatement.

**C. Conclusions.**

This study presents some insights into the extent of the externality problem associated with agricultural production in the Willamette Valley. This insight includes identifying the differences between farm types in pollution problems and economic factors affecting their control. It also sheds light on the relative effectiveness of various policies both for control of pollution and their effects on farm-level profits and changes in production efficiency.

A central issue surrounding this dissertation is the existence and ownership of property rights, specifically the rights to water resources. Historically and traditionally, in many parts of the United States where agricultural production takes place, farmers have maintained an implicit right to water. The growing awareness of externalities by the general public, particularly non-point source pollution, and greater demands for other uses of the resource have called into question the ownership issue. While much of the past efforts to control pollution (in the form of soil erosion and sediment) have focused on voluntary efforts and subsidy, there is a more widespread use of regulatory measures which contain an inherent redefinition of rights, away from farmers.

The use of the measures tested here need not be punitive in nature. For example, charges and input taxes result in tax revenues collected by a governmental body and presumably redistributed in other forms throughout society.

If these measures were not intended to be punitive, it is possible that a lump-sum "rebate" program could be instituted, whereby the charges were imposed so as to induce abating behavior, and the revenues returned directly to farmers.

The decisions regarding ultimate ownership rights will be played out in the political process, at the federal, state, and in some cases the local level. This research has usefulness to policy makers as well as farmers. The choice of policy instrument, targeted abatement level, and distribution of taxes or subsidies implicitly determines ownership of rights as well as who pays to correct the externality. It is also a reflection of the demand by "society" for nutrient-free water. Such determinations, and their implications, need to be understood by policy makers before implementation. Farmers also need to become apprised of the effects of particular policies on profits and farm operations, as well as the production and management options available to them to meet the pollution control objectives.

Perhaps the most important lesson derived from this research is to foster an appreciation of the complexity of addressing externality problems, particularly non-point source pollution. While the process of acquiring information, conducting analyses, and developing policy recommendations can be tedious and time consuming, its importance in the context of the achieving the goals of society cannot be underestimated.

# BIBLIOGRAPHY

American Agricultural Economics Association. 1986. Soil erosion and soil conservation policy in the United States. Soil Conservation Policy Task Force, Occasional Paper No. 2, January.

Austin, T.A. and J.L. Baker. 1989. Agriculture and groundwater quality. In: *Water Resources Update* No. 80, Autumn.

Bailey, G.W. 1968. Role of soils and sediment in water pollution control. Report by U.S. Department of Interior, Federal Water Pollution Control Administration, Southeast Water Laboratory.

Bailey, G.W. and R.R. Swank, Jr. 1983. Modeling agricultural non-point source pollution: a research perspective. In: F.W. Schaller and G.W. Bailey, eds. Agricultural management and water quality. Iowa State University Press, Ames, Iowa.

Batie, S. 1988. Agriculture as the problem: the case of groundwater contamination. *Choices* 3(3):4-7.

Baumol, W.J. and W.E. Oates. 1975. The theory of environmental policy. Prentice Hall, Inc., Englewood Cliffs, New Jersey.

Boadway, R.W. and N. Bruce. 1984. Welfare economics. Basil Blackwell, Inc., New York, New York.

Brooke, A., D. Kendrick, and A. Meeraus. 1988. GAMS: A User's Guide. Scientific Press, Redwood City, California.

Burt, Oscar. 1981. Farm level economics of soil conservation in the Palouse area of the Northwest. *American Journal of Agricultural Economics* 63:83-92.

Buttel, F.H., G.W. Gillespie, Jr., R. Janke, B. Caldwell, and M. Sarrantonio. 1986. Reduced-input agricultural systems: Rationale and prospects. *American Journal of Alternative Agriculture* 1(2):58-64.

Campbell, D.E. 1987. Resource allocation mechanisms. Cambridge University Press, New York.

Chesters and Schierow. 1985. A primer on nonpoint pollution. *Journal of Soil and Water Conservation* 40:14-18.

Christensen, L.A. 1983. Water quality: a multidisciplinary perspective. In: T.L. Napier, et al., eds. Water resources research: problems and potentials for agriculture and rural communities. Soil Conservation Society of America, Ankeny, Iowa.

Christensen, N. 1987. Soil Scientist, Oregon State University, personal communcation, October.

Clark, E.H., II, J.A. Haverkamp, and W. Chapman. 1985. Eroding soils: the off-farm impacts. The Conservation Foundation, Washington, D.C.

Coase, R. H. 1960. The problem of social cost. *Journal of Law and Economics* 3(1). October.

Colacicco, D., T. Osborn, and K. Alt. 1989. Economic damage from soil erosion. *Journal of Soil and Water Conservation* 44:35-38.

Conklin, F.S. 1989. Agricultural economist, Oregon State University, personal communication, 21 September.

Conklin, F.S., W.C. Young III, and H.W. Youngberg. 1989. Burning grass seed fields in Oregon's Willamette Valley: The search for solutions. OSU Extension Miscellaneous 8397, January.

Council on Environmental Quality. 1979. Environmental Quality; the tenth annual report of the CEQ. Government Printing Office, Washington, D.C.

Cross, T., J. Burt, and D. McGrath. 1988a. Enterprise budget: Sweet corn, Willamette Valley region. OSU Extension Service EM 8376, April.

Cross, T., J. Burt, and D. McGrath. 1988b. Enterprise budget: Bush beans, Willamette Valley region. OSU Extension Service EM 8380, April.

Crosson, P.R. 1985. Agricultural land: A question of values. *Agricultural and Human Values Journal*, Fall.

Crosson, P.R. 1989. What is alternative agriculture? *American Journal of Alternative Agriculture* 4(1):28-31.

Crosson, P.R. and S. Brubaker. 1982. Resource and environmental effects of U.S. agriculture. Resources For the Future, Washington, D.C.

Crutchfield, S.R., D.E. Ervin, and R.J. Brazee. 1989. Agriculture and its relationship to water quality: a conceptual framework for integrated analysis. Paper presented at the AAEA Annual Meetings, Baton Rouge, Louisiana, August.

Daberkow, S.G. and K.H. Reichelderfer. 1988. Low-input agriculture: trends, goals and prospects for input use. Paper presented at AAEA Annual Meetings, Knoxville, Tennessee, August.

Dempster, T.H. and J.H. Stierna. 1979. Procedure for economic evaluation of best management practices. In: Best Management Practices for Agriculture and Silviculture, Proceedings, 1978 Cornell Agricultural Waste Management Conference. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, pp. 383-391.

Domanico, J.L., P. Madden, and E.J. Partenheimer. 1986. Income effects of limiting soil erosion under organic, conventional, and no-till systems in eastern Pennsylvania. *American Journal of Alternative Agriculture* 1(2):75-82.

Doran, J.W., D.G. Fraser, M.N. Culik, and W.C. Liebhardt. 1987. Influence of alternative and conventional agricultural management on soil microbial processes and nitrogen availability. *American Journal of Alternative Agriculture* 2(3):99-106.

Duttweiler, D.W. and H.P. Nicholson. 1983. Environmental problems and issues of agricultural non-point source pollution. In: F.W. Schaller and G.W. Bailey, eds. Agricultural management and water quality. Iowa State University Press, Ames, Iowa.

Edwards, C.A. 1987. The concept of integrated systems in lower input/sustainable agriculture. *American Journal of Alternative Agriculture* 2(4):148-152.

Eichers, T.R., P. Andrilenas, and T.W. Anderson. 1978. Farmers' use of pesticides in 1976. USDA-ERS, Agricultural Report no. 418.

Fairchild, Deborah. 1987. Groundwater quality and agricultural practices. Lewis Publishing Co., Chelsea, Michigan.

Ferguson, G.A., S.L. Klausner, W.S. Reid. 1988. Synchronizing nitrogen additions with crop demand to protect groundwater. In: *NY Food and Life Sciences Quarterly* 18(1,2).

Giannessi and Peskin. 1981. Analysis of national water pollution control policies (I and II). *Water Resources Research* 17(4):796-821.

Goldstein, W.A. and D. Young. 1987. An economic comparison of a conventional and a low-input cropping system in the Palouse. Scientific Paper No. 7703, Project 5514, Washington State University, Pullman, Washington, June.

Gordon, H.S. 1954. The economic theory of a common-property resource: The fishery. *Journal of Political Economy* 62(2).

Hallberg, G.R. 1987. Agricultural chemicals in ground water: Extent and implications. *American Journal of Alternative Agriculture* 2(1):3-15.

Halstead, J.M., S.S. Batie, D.B. Taylor, C.D. Heatwole, P.L. Diebel, and R.A. Kramer. 1989. Managing agricultural nitrate contamination of ground water: impacts of uncertainty on policy formulation. Paper presented at AAEA meetings in Baton Rouge, Louisiana, August.

Heimlich, R.E. and C.W. Ogg. 1982. Evaluation of soil erosion and pesticide exposure control strategies. *Journal of Economics and Environmental Management* 9:279-288.

Helfand, G.E. 1989. The effects on production and profits of different pollution control standards. Paper presented at AAEA Annual Meetings, Baton Rouge, Louisiana, August.

Helmers, G.A., M.R. Langemeier, and J. Atwood. 1986. An economic analysis of alternative cropping systems for east-central Nebraska. *American Journal of Alternative Agriculture* 1(4):153-158.

Huddleston, H. 1989. Extension soil scientist, Oregon State University, personal communication, 25 August and 17 December.

Hughes, D.W. and W.R. Butcher. 1989. Soil conservation policies: A rights oriented and benefit-cost analysis. Paper presented at AAEA Annual Meetings, Baton Rouge, Louisiana, August.

Johnson, G.V. 1987. Soil testing as a guide to prudent use of nitrogen fertilizers in Oklahoma agriculture. In: Fairchild, Deborah, ed. Groundwater quality and agricultural practices. Lewis Publishing Co., Chelsea, Michigan, 1987.

Karow, R. 1989. Extension crop scientist, Oregon State University, personal communication, 22 August.

Keeny, D.K. 1982. Nitrogen management for maximum efficiency and minimum pollution. In: F.J. Stevenson, ed. Nitrogen in Agricultural Soils. Agronomy Monograph 22, American Society of Agronomy, Madison, Wisconson, pp. 605-649.

Lockeretz, W. 1988. Open questions in sustainable agriculture. *American Journal of Alternative Agriculture* 3(4):174-181.

Madden, J.P. 1989. What is alternative agriculture? *American Journal of Alternative Agriculture* 4(1):32-34.

McCarl, B. and T. El-Nazer. 1986. The choice of crop rotation: A modeling approach and case study. *American Journal of Agricultural Economics* 68(1):127-136.

McGrann, J.M., K.D. Olson, T.A. Powell, and T.R. Nelson. 1986. Microcomputer Budget Management System user manual. Dept. of Agricultural Economics, Texas A & M University, College Station, Texas.

Miles, S.F. 1989. Oregon county and state agricultural estimates. Special Report 790, Oregon State University Extension Service, January.

Miranowski, J.A. 1983. Agricultural impacts on environmental quality. In: T.L. Napier, et al., eds. Water resources research: problems and potentials for agriculture and rural communities. Soil Conservation Society of America, Ankeny, Iowa.

Murtagh, B.A. and M.A. Saunders. 1987. MINOS 5.1 User's Guide. Report SOL 83-20R, Stanford University. December 1983, revised January 1987.

National Oceanographic and Atmospheric Administration. 1985. Climates of the States. Gale Research Company, Detroit.

National Research Council. 1989. Alternative Agriculture. National Academy Press, Washington, D.C.

Omernik, J.M. 1977. Non-point source - stream nutrient level relationships: A nationwide study. Ecological Research Series, U.S. Environmental Protection Agency, EPA-600/3-77-105, Corvallis, OR, September.

Oregon Department of Environmental Quality. 1988. Oregon environmental atlas. Portland State University Press.

Oregon State University Extension Service. 1988. Profiles of commercial agriculture for the southern Willamette Valley. Special Report 696, Oregon State University, Corvallis.

OSU Extension Service. 1975a. Improved dryland pasture, Willamette Valley. Enterprise budget, Department of Agricultural and Resource Economics, February.

OSU Extension Service. 1975b. Spring barley, Willamette Valley. Enterprise budget, Department of Agricultural and Resource Economics, March.

OSU Extension Service. 1975c. Improved hill-land pasture, Mid-Willamette Valley. Enterprise budget, Department of Agricultural and Resource Economics, June.

OSU Extension Service. 1976a. Irrigated pasture, Mid-Willamette Valley. Enterprise budget, Department of Agricultural and Resource Economics, February.

OSU Extension Service. 1976b. Fall oats, Mid-Willamette Valley. Enterprise budget, Department of Agricultural and Resource Economics, March.

OSU Extension Service. 1977. Douglas fir Christmas trees, Mid-Willamette Valley. Enterprise budget, Department of Agricultural and Resource Economics, January.

Papendick, R.I., L.F. Elliot, and J.F. Power. 1987. Alternative production systems to reduce nitrates in ground water. *American Journal of Alternative Agriculture* 2(1):19-24.

Pierce, F.J., R.H. Dowdy, W.E. Larson, and W.A.P. Graham. 1984. Soil productivity in the Corn Belt: an assessment of erosion's long-term effects. *Journal of Soil and Water Conservation* 39(2):131-136.

Randall, A. 1983. The problem of market failure. *Natural Resources Journal* 23(1):131-148.

Ribaudo, M.O. 1986. Reducing soil erosion: Off-site benefits. USDA/ERS Ag. Econ. Report No. 561, Washington DC, September.

Ruffner, J.A. and F.E. Bair, eds. 1987. Weather of U.S. cities, vol. 2. Gale Research Company, Detroit.

Ryan, J.T., F.S. Conklin, and J.A. Edwards. 1981. Demand and supply in the Oregon grass seed industry: An economic analysis. OSU Agricultural Experiment Station Bulletin 652, Corvallis, September.

Scott, N.R. 1988. Groundwater: protecting our valuable resource. *NY Food and Life Sciences Quarterly* 18(1,2).

Setia, P. and R. Magleby. 1987. An economic analysis of agricultural non-point pollution control alternatives. *Journal of Soil and Water Conservation* 42(6):427-434.

Shortle, J.S. and J.W. Dunn. 1986. The relative efficiency of agricultural source water pollution control policies. *American Journal of Agricultural Economics*, August, 1986:668-677.

Soil Conservation Society of America. 1982. Resource conservation glossary. Third edition, Ankeny, Iowa.

Taylor, M.L. and S.F. Miller. 1987. Offsite damages of soil erosion: Reasons for their consideration. Presented at the Annual STEEP Review, Richland, WA, 7 January.

Taylor, M.L., T. Cross, and G. Gingrich. 1989a. Enterprise budget: Winter wheat, Willamette Valley. OSU Extension Service, EM 8424, July.

Taylor, M.L., T. Cross, and M. Mellbye. 1989b. Enterprise budget: Annual ryegrass (no-till), Willamette Valley. OSU Extension Service, EM 8423, July.

Thomas, H.R. 1989. Economist, Soil Conservation Service West National Technical Center, Portland, Oregon, personal communication, August.

Tinbergen, J. 1952. On the theory of economic policy. North-Holland Publishing Co., Amsterdam.

U.S. Department of Agriculture. 1980. Report and recommendations on organic farming. U.S.D.A. Study Team on Organic Farming Report, U.S. Government Printing Office, Washington, DC, July.

U.S. Department of Agriculture. 1987. The magnitude and costs of groundwater contamination from agricultural chemicals: A national perspective. Staff Report AGES870318. Economic Research Service, Washington, DC.

U.S. Department of Agriculture / Soil Conservation Service. 1983. Water quality field guide. SCS-TP-160, Washington, D.C., September.

U.S. Department of Commerce. 1983. Census for 1980. U.S. Government Printing Office, Washington DC, November.

U.S. Department of Commerce. 1984. Census of Agriculture, 1982. U.S. Government Printing Office, Washington DC, April.

U.S. Department of Commerce. 1989. Census of Agriculture, 1987 (prelim.). U.S. Government Printing Office, Washington DC.

U.S. Environmental Protection Agency. 1984. Report to Congress: Nonpoint source pollution in the U.S. Office of Water Program Operations, Water Planning Division, Washington, D.C.

Wagenet, R.J. and J.L. Hutson. 1988. Predicting pesticide and fertilizer movement to groundwater. In: *NY Food and Life Sciences Quarterly* 18(1,2).

Walker, D.R. and J.P. Hoehn. 1988. Rural water supply and the economic cost of groundwater contamination: The case of nitrates. Staff paper No. 88-67. Department of Agricultural Economics, Michigan State University, July.

White, W.C. and H. Plate. 1979. Best management practices for fertilizer use. In: R. C. Loehr, et al., eds. Best Management Practices for Agriculture and Silvaculture. Ann Arbor Sci. Publ., Inc., Ann Arbor, Michigan.

Williams, J.R., P.T. Dyke, W.W. Fuchs, V.W. Benson, O.W. Rice, and E.D. Taylor. 1989. EPIC: The erosion-productivity impact calculator; Volume II: User manual. USDA/ARS; Grassland, Soil and Water Research Laboratory, Temple, Texas. Draft.

Williams, J.R., C.A. Jones, and P.T. Dyke. 1984. A modeling approach to determining the relationship between erosion and soil productivity. *Transactions of the ASAE* 27(1):129-144.

Yoo, K.H. and J.T. Touchton. 1989. Runoff and soil loss by crop growth stage under three cotton tillage systems. *Journal of Soil and Water Conservation* 44(3):225-228.

Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson. 1989. AGNPS: A nonpoint source pollution model for evaluating agricultural watersheds. *Journal of Soil and Water Conservation* 44(2):168-172.

Young, W. 1989. Extension agronomist, Oregon State University, personal communication, 8 November.

Youngberg, H., H. Hickerson, and S. Miles. 1985a. Enterprise data sheet: Perennial ryegrass (Forage type), Willamette Valley. OSU Extension Service, Corvallis, November.

Youngberg, H., H. Hickerson, and S. Miles. 1985b. Enterprise data sheet: Tall fescue seed, Willamette Valley. OSU Extension Service, Corvallis, November.

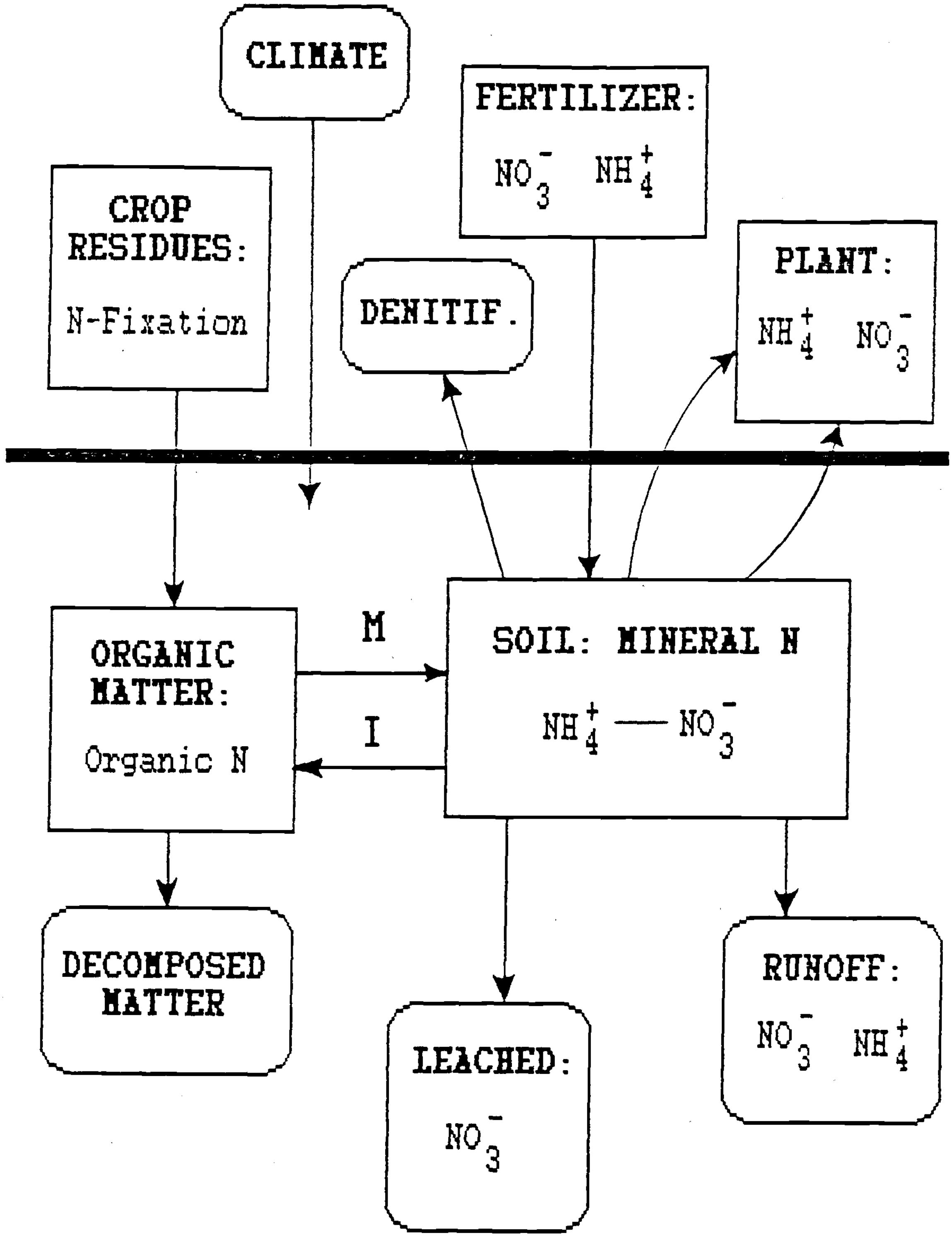
# APPENDICES

## APPENDIX A: Nitrogen processes

Determining levels and fate of chemical fertilizers in soil is complex and tedious, and is affected by many factors, including soil characteristics, climate, and management. A generalized description of the nitrogen process is included in this section to aid in the discussion of nitrogen and nitrate pollution.

Soil nitrogen consists of two components (figure A-1): (1) a mobile inorganic constituent composed mainly of nitrate ($NO_3-$) which moves readily with water; and (2) an immobile organic compound that is slowly mineralized to $NO_3-$ by a series of microbial reactions. Plants absorb N mainly as $NO_3-$.

The key biological transformations of N are: (1) immobilization through the assimilation of inorganic forms of N by plants and microorganisms to form organic N compounds; (2) ammonification or mineralization, the decomposition of organic N to $NH_4+$; (3) nitrification or the microbial oxidation of NH4+ to $NO_2-$ and $NO_3-$; (4) denitrification, the reduction of $NO_3-$ or $NO_2-$ to $N_20$ and $N_2$; and (5) nitrogen fixation, the reduction of $N_2$ to $NH_3$. Important chemical reactions in the soil N cycle are: (1) ammonia volatilization or sorption which is the release or uptake of atmospheric $NH_3$ by soils or plants; (2) ammonium exchange or the rapid and reversible exchange of $NH_4+$ from soil cation exchange sites to soil solution; (3) ammonium


CLIMATE
FERTILIZER:
$NO_3^-$ $NH_4^+$
CROP RESIDUES:
N-Fixation
DENITIF.
PLANT:
$NH_4^+$ $NO_3^-$
M
I
ORGANIC MATTER:
Organic N
SOIL: MINERAL N
$NH_4^+$ — $NO_3^-$
DECOMPOSED MATTER
LEACHED:
$NO_3^-$
RUNOFF:
$NO_3^-$ $NH_4^+$

fixation, the entrapment of $NH_4+$ in the interlayers of nonexpanding 2:1 clay minerals such that it is only slowly released; and (4) chemical nitrification or chemodenitrification, the reaction of $NO_2-$ (or $HNO_2$) with soil constituents at acid pH or under elevated temperatures to yield $N_2$ or N oxides [Keeny, p. 51].

Surface runoff will also contain soluble N, primarily $NH_4+$ and $NO_3-$. Precipitation adds "significant" inorganic N (about 5 to 10 kg/ha/yr); usually more added in precipitation than is lost from a watershed in surface runoff and base flow. Ammonium will be retained in the soil cation exchange sites and may nitrify, erode with particles, or reenter the soluble N fraction through equilibrium with other cations during sediment transport. Nitrate can move on through the soil and enter into the soil N cycle, reappear in surface flow downslope, or be leached to the ground water table. Runoff can also obtain additional inorganic N from vegetation as well as from the N at the soil-water interface.

# APPENDIX B: Summarized enterprise budgets

WINTER WHEAT - CONVENTIONAL TILLAGE

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Disc (3X) | 8/15-9/15 | 0.750 | 165hp | 5.94 | 10.95 | 10.25 | | | | | 16.89 |
| Plow | 9/10-9/20 | 0.250 | 165hp | 2.72 | 6.23 | 6.43 | | | | | 8.95 |
| Drill/harrow | 10/10-10/20 | 0.167 | 111hp | 1.81 | 3.53 | 3.37 | | 200 | | 12.50 | 39.84 |
| Cultipack | 10/20-10/25 | 0.100 | 165hp | 1.09 | 1.10 | 1.86 | | | | | 2.19 |
| Dixon harrow | 10/25-10/30 | 0.080 | 165hp | 0.87 | 1.23 | 1.41 | | | | | 2.10 |
| Fall herbicide | 10/30-11/5 | | | | | | 7.40 | | | 5.00 | 12.40 |
| Winter fertilize | 2/5-2/25 | | | | | | | | 35 | 5.00 | 13.75 |
| Winter herbicide | 2/5-2/25 | | | | | | 15.50 | | | 5.00 | 20.50 |
| Spring fertilize | 3/25-4/5 | | | | | | | | 110 | 5.00 | 32.50 |
| Spring herbicide | 3/25-4/5 | | | | | | 3.57 | | | 5.00 | 8.57 |
| Spring fungicide | 4/20-4/30 | | | | | | 9.00 | | | 5.00 | 14.00 |
| Combine | 7/10-7/20 | 0.286 | 225hp | 2.25 | 15.16 | 9.40 | | | | | 17.41 |
| Haul grain | 7/10-7/20 | | | 0.25 | 1.19 | 2.48 | | | | | 1.44 |
| Other | | | | 7.83 | 2.54 | 3.28 | | | | 7.00 | 17.37 |
| Interest | | | | | | | | | | 20.60 | |
| Total variable cost | | | | | | | | | | | 207.91 |
| TOTALS | | | | 22.76 | 41.93 | 38.48 | 35.47 | 22.00 | 36.25 | 70.10 | 266.99 |

WINTER WHEAT - REDUCED TILLAGE

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Disc (3X) | 8/15-9/15 | 0.750 | 165hp | 5.94 | 10.95 | 10.25 | | | | | 16.89 |
| Drill/harrow | 10/10-10/20 | 0.167 | 111hp | 1.81 | 3.53 | 3.37 | | 200 | | 12.50 | 39.84 |
| Cultipack | 10/20-10/25 | 0.100 | 165hp | 1.09 | 1.10 | 1.86 | | | | | 2.19 |
| Dixon harrow | 10/25-10/30 | 0.080 | 165hp | 0.87 | 1.23 | 1.41 | | | | | 2.10 |
| Fall herbicide | 10/30-11/5 | | | | | | 7.40 | | | 5.00 | 12.40 |
| Winter fertilize | 2/5-2/25 | | | | | | | | 35 | 5.00 | 13.75 |
| Winter herbicide | 2/5-2/25 | | | | | | 15.50 | | | 5.00 | 20.50 |
| Spring fertilize | 3/25-4/5 | | | | | | | | 110 | 5.00 | 32.50 |
| Spring herbicide | 3/25-4/5 | | | | | | 3.57 | | | 5.00 | 8.57 |
| Spring fungicide | 4/20-4/30 | | | | | | 9.00 | | | 5.00 | 14.00 |
| Combine | 7/10-7/20 | 0.286 | 225hp | 2.25 | 15.16 | 9.40 | | | | | 17.41 |
| Haul grain | 7/10-7/20 | | | 0.25 | 1.19 | 2.48 | | | | | 1.44 |
| Other | | | | 7.83 | 2.54 | 3.28 | | | | 7.00 | 17.37 |
| Interest | | | | | | | | | | 20.60 | |
| Total variable cost | | | | | | | | | | | 198.96 |
| TOTALS | | | | 20.04 | 35.70 | 32.05 | 35.47 | 22.00 | 36.25 | 70.10 | 251.61 |

WINTER WHEAT - NO-TILLAGE

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pre-Herbicide | 8/15-9/15 | | | | | | 10.00 | | | 4.00 | 14.00 |
| Drill/harrow | 10/10-10/20 | 0.167 | 111hp | 1.81 | 3.53 | 3.37 | | 200 | | 12.50 | 39.84 |
| Cultipack | 10/20-10/25 | 0.100 | 165hp | 1.09 | 1.10 | 1.86 | | | | | 2.19 |
| Dixon harrow | 10/25-10/30 | 0.080 | 165hp | 0.87 | 1.23 | 1.41 | | | | | 2.10 |
| Fall herbicide | 10/30-11/5 | | | | | | 7.40 | | | 5.00 | 12.40 |
| Winter fertilize | 2/5-2/25 | | | | | | | | 35 | 5.00 | 13.75 |
| Winter herbicide | 2/5-2/25 | | | | | | 15.50 | | | 5.00 | 20.50 |
| Spring fertilize | 3/25-4/5 | | | | | | | | 110 | 5.00 | 32.50 |
| Spring herbicide | 3/25-4/5 | | | | | | 3.57 | | | 5.00 | 8.57 |
| Spring fungicide | 4/20-4/30 | | | | | | 9.00 | | | 5.00 | 14.00 |
| Combine | 7/10-7/20 | 0.286 | 225hp | 2.25 | 15.16 | 9.40 | | | | | 17.41 |
| Haul grain | 7/10-7/20 | | | 0.25 | 1.19 | 2.48 | | | | | 1.44 |
| Other | | | | 7.83 | 2.54 | 3.28 | | | | 7.00 | 17.37 |
| Interest | | | | | | | | | | 20.60 | |
| Total variable cost | | | | | | | | | | | 196.07 |
| TOTALS | | | | 14.10 | 24.75 | 21.80 | 45.47 | 22.00 | 36.25 | 74.10 | 238.47 |

ANNUAL RYEGRASS - CONVENTIONAL TILLAGE

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Plow | 8/15-8/25 | 0.250 | 165hp | 2.72 | 6.23 | 6.43 | | | | | 8.95 |
| Harrow | 8/25-9/5 | 0.080 | 165hp | 0.87 | 1.23 | 1.41 | | | | | 2.10 |
| Cultipack | 8/25-9/10 | 0.100 | 165hp | 1.09 | 1.10 | 1.86 | | | | | 2.19 |
| Drill | 9/5-9/15 | 0.167 | 111hp | 1.81 | 2.95 | 2.75 | | 140 | | 4.25 | 24.41 |
| Fertilize | 3/20-4/5 | | | | | | | | 135 | 5.00 | 38.75 |
| Spring Herbicide | 4/10-4/20 | | | | | | 2.55 | | | 5.00 | 7.55 |
| Swath | 7/1-7/10 | | | 1.80 | 6.02 | 1.92 | | | | | 7.82 |
| Combine | 7/10-7/25 | 0.286 | 225hp | 2.25 | 15.16 | 9.40 | | | | | 17.41 |
| Haul seed | 7/10-7/25 | | | 0.27 | 1.26 | 2.63 | | | | | 1.53 |
| Border prep. | 8/1-8/15 | 0.033 | 165hp | 0.31 | 0.71 | 0.74 | | | | | 1.02 |
| Field burn | 8/5-8/20 | 0.100 | both | 0.70 | 0.43 | 0.89 | | | | 3.50 | 4.63 |
| Other | | | | 7.83 | 2.54 | 3.28 | | | | 80.77 | 91.14 |
| Interest | | | | | | | | | | 10.24 | |
| Total variable cost | | | | | | | | | | | 207.50 |
| TOTALS | | | | 19.65 | 37.63 | 31.31 | 2.55 | 15.40 | 33.75 | 108.76 | 249.05 |

ANNUAL RYEGRASS - NO-TILLAGE

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Plant | 8/25-9/5 | 0.167 | 111hp | 1.81 | 2.95 | 2.75 | | 140 | | 4.25 | 24.41 |
| Fertilize | 3/20-4/5 | | | | | | | | 135 | 5.00 | 38.75 |
| Spring Herbicide | 4/10-4/20 | | | | | | 2.55 | | | 5.00 | 7.55 |
| Swath | 7/1-7/10 | | | 1.80 | 6.02 | 1.92 | | | | | 7.82 |
| Combine | 7/10-7/25 | 0.286 | 225hp | 2.25 | 15.16 | 9.40 | | | | | 17.41 |
| Haul seed | 7/10-7/25 | | | 0.27 | 1.26 | 2.63 | | | | | 1.53 |
| Border prep. | 8/1-8/15 | 0.033 | 165hp | 0.31 | 0.71 | 0.74 | | | | | 1.02 |
| Field burn | 8/5-8/30 | 0.100 | both | 0.70 | 0.43 | 0.89 | | | | 3.50 | 4.63 |
| Other | | | | 7.83 | 2.54 | 3.28 | | | | 80.77 | 91.14 |
| Interest | | | | | | | | | | 10.24 | |
| Total variable cost | | | | | | | | | | | 194.26 |
| TOTALS | | | | 14.97 | 29.07 | 21.61 | 2.55 | 15.40 | 33.75 | 108.76 | 226.11 |

PERENNIAL RYEGRASS - ESTABLISHMENT

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Plow | 8/15-8/25 | 0.250 | 165hp | 2.72 | 6.23 | 6.43 | | | | | 8.95 |
| Disc (2X) | 8/25-9/5 | 0.500 | 165hp | 3.96 | 7.30 | 6.83 | | | | | 11.26 |
| Cultipack (3X) | 8/25-9/10 | 0.300 | 165hp | 3.27 | 3.29 | 5.56 | | | | | 6.56 |
| Plant | 9/5-9/15 | 0.167 | 111hp | 1.81 | 2.95 | 2.75 | | 200 | | 9.00 | 35.76 |
| Other | | | | 7.83 | 2.54 | 3.28 | | | | 20.00 | 30.37 |
| Interest | | | | | | | | | | 10.24 | |
| Total variable cost | | | | | | | | | | | 92.90 |
| TOTALS | | | | 19.59 | 22.31 | 24.85 | 0.00 | 22.00 | 0.00 | 39.24 | 127.99 |

PERENNIAL RYEGRASS - PRODUCTION

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fall herbicide | | | | | | | 3.60 | | | 5.00 | 8.60 |
| Fall fertilize | | | | | | | | 167 | | 5.00 | 23.37 |
| Spring Herbicide | 4/10-4/20 | | | | | | 3.20 | | | 5.00 | 8.20 |
| Fertilize | 3/20-4/5 | | | | | | | | 100 | 10.00 | 35.00 |
| Rouging | | | | | | | | | | 6.00 | 6.00 |
| Spring fung.(2X) | | | | | | | 30.00 | | | 10.00 | 40.00 |
| Swath | 7/1-7/10 | | | 1.80 | 6.02 | 1.92 | | | | | 7.82 |
| Combine | 7/10-7/25 | 0.286 | 225hp | 2.25 | 15.16 | 9.40 | | | | | 17.41 |
| Haul seed | 7/10-7/25 | | | 0.27 | 1.26 | 2.63 | | | | | 1.53 |
| Border prep. | 8/1-8/15 | 0.033 | 165hp | 0.31 | 0.71 | 0.74 | | | | | 1.02 |
| Field burn | 8/5-8/20 | 0.100 | both | 0.70 | 0.43 | 0.89 | | | | 3.50 | 4.63 |
| Other | | | | 7.83 | 2.54 | 3.28 | | | | 80.77 | 91.14 |
| Interest | | | | | | | | | | 10.24 | |
| Total variable cost | | | | | | | | | | | 244.72 |
| TOTALS | | | | 13.16 | 26.12 | 18.86 | 36.80 | 18.37 | 25.00 | 135.51 | 273.82 |

TALL FESCUE - ESTABLISHMENT

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Plow | 8/15-8/25 | 0.250 | 165hp | 2.72 | 6.23 | 6.43 | | | | | 8.95 |
| Lime | | | | | | | | | | 78.00 | 78.00 |
| Disc (2X) | 8/25-9/5 | 0.500 | 165hp | 3.96 | 7.30 | 6.83 | | | | | 11.26 |
| Cultipack (3X) | 8/25-9/5 | 0.300 | 165hp | 3.27 | 3.29 | 5.56 | | | | | 6.56 |
| Plant | 9/5-9/15 | 0.167 | 111hp | 1.81 | 2.95 | 2.75 | | 200 | | 38.00 | 64.76 |
| Other | | | | 7.83 | 2.54 | 3.28 | | | | 20.00 | 30.37 |
| Interest | | | | | | | | | | 10.24 | |
| Total variable cost | | | | | | | | | | | 199.90 |
| TOTALS | | | | 19.59 | 22.31 | 24.85 | 0.00 | 22.00 | 0.00 | 146.24 | 234.99 |

TALL FESCUE - PRODUCTION

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fall herbicide | | | | | | | 8.20 | | | 5.00 | 13.20 |
| Fall fertilize | | | | | | | | 167 | | 5.00 | 5.00 |
| Spring Herbicide | 4/10-4/20 | | | | | | 4.50 | | | 5.00 | 9.50 |
| Fertilize | 3/20-4/5 | | | | | | | | 100 | 10.00 | 35.00 |
| Fungicide | | | | | | | 15.00 | | | 5.00 | 20.00 |
| Swath | 7/1-7/10 | | | 1.80 | 6.02 | 1.92 | | | | | 7.82 |
| Combine | 7/10-7/25 | 0.286 | 225hp | 2.25 | 15.16 | 9.40 | | | | | 17.41 |
| Haul seed | 7/10-7/25 | | | 0.27 | 1.26 | 2.63 | | | | | 1.53 |
| Border prep. | 8/1-8/15 | 0.033 | 165hp | 0.31 | 0.71 | 0.74 | | | | | 1.02 |
| Field burn | 8/5-8/20 | 0.100 | both | 0.70 | 0.43 | 0.89 | | | | 3.50 | 4.63 |
| Other | | | | 7.83 | 2.54 | 3.28 | | | | 80.77 | 91.14 |
| Interest | | | | | | | | | | 10.24 | |
| Total variable cost | | | | | | | | | | | 206.25 |
| TOTALS | | | | 13.16 | 26.12 | 18.86 | 27.70 | 18.37 | 25.00 | 124.51 | 253.72 |

SWEET CORN

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pre-herb's (2X) | 3/10-5/10 | | 120hp | 2.40 | 5.31 | | 57.75 | | | | 65.46 |
| Plow | 4/1-4/20 | | 150hp | 2.82 | 6.09 | | | | | | 8.91 |
| Disc | 4/15-5/5 | | 120hp | 1.54 | 3.13 | | | | | | 4.67 |
| Harrow | 4/25-5/10 | | 120hp | 1.21 | 1.81 | | | | | | 3.02 |
| Plant | 5/10-5/25 | | 85hp | 3.39 | 6.06 | | | | 51 | 65.29 | 87.49 |
| Fertilize | 6/10-6/20 | | 50hp | 0.85 | 0.55 | | | | 150 | | 38.90 |
| Cultivate | 6/15-6/30 | | 150hp | 1.21 | 2.07 | | | | | | 3.28 |
| Irrigate | | | | 51.84 | | | | | | 43.05 | 94.89 |
| Custom top/pick | 8/1-8/20 | | | | | | | | | 79.00 | 79.00 |
| Haul | 8/1-8/20 | | | 9.00 | 5.81 | | | | | | 14.81 |
| Other eq., lime | | | | | 6.69 | | | | | 8.62 | 15.31 |
| Shredding | 10/1-10/30 | | 120hp | 1.88 | 3.79 | | | | | | 5.67 |
| Subsoil | 10/5-11/10 | | 150hp | 0.40 | 0.70 | | | | | | 1.10 |
| Disc | 10/15-11/15 | | 120hp | 1.54 | 3.13 | | | | | | 4.67 |
| Interest & fixed | | | | | | 92.36 | | | | 16.44 | |
| Total variable cost | | | | | | | | | | | 427.18 |
| TOTALS | | | | 78.08 | 45.14 | 92.36 | 57.75 | 0.00 | 50.25 | 212.40 | 535.98 |

SWEET CORN after CLOVER

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pre-herb's (2X) | 3/10-5/10 | | 120hp | 2.40 | 5.31 | | 57.75 | | | | 65.46 |
| Plow | 4/1-4/20 | | 150hp | 2.82 | 6.09 | | | | | | 8.91 |
| Disc | 4/15-5/5 | | 120hp | 1.54 | 3.13 | | | | | | 4.67 |
| Harrow | 4/25-5/10 | | 120hp | 1.21 | 1.81 | | | | | | 3.02 |
| Plant | 5/10-5/25 | | 85hp | 3.39 | 6.06 | | | | 51 | 65.29 | 87.49 |
| Fertilize | 6/10-6/20 | | 50hp | 0.85 | 0.55 | | | | 60 | | 16.40 |
| Cultivate | 6/15-6/30 | | 150hp | 1.21 | 2.07 | | | | | | 3.28 |
| Irrigate | | | | 51.84 | | | | | | 43.05 | 94.89 |
| Custom top/pick | 8/1-8/20 | | | | | | | | | 79.00 | 79.00 |
| Haul | 8/1-8/20 | | | 9.00 | 5.81 | | | | | | 14.81 |
| Other eq., lime | | | | | 6.69 | | | | | 8.62 | 15.31 |
| Shredding | 10/1-10/30 | | 120hp | 1.88 | 3.79 | | | | | | 5.67 |
| Subsoil | 10/5-11/10 | | 150hp | 0.40 | 0.70 | | | | | | 1.10 |
| Disc | 10/15-11/15 | | 120hp | 1.54 | 3.13 | | | | | | 4.67 |
| Interest & fixed | | | | | | 92.36 | | | | 16.44 | |
| Total variable cost | | | | | | | | | | | 404.68 |
| TOTALS | | | | 78.08 | 45.14 | 92.36 | 57.75 | 0.00 | 27.75 | 212.40 | 513.48 |

BUSH BEANS

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Plow | 4/1-4/20 | | 150hp | 2.82 | 6.09 | | | | | | 8.91 |
| Disc | 4/15-5/5 | | 120hp | 1.54 | 3.13 | | | | | | 4.67 |
| Harrow | 4/25-5/10 | | 120hp | 1.21 | 1.81 | | | | | | 3.02 |
| Pre-plant inc. | 3/10-5/10 | | 120hp | 2.12 | 5.13 | | 38.58 | 533 | | | 104.50 |
| Roll | 5/10-5/25 | | 120hp | 1.36 | 1.00 | | | | | | 2.36 |
| Plant | 5/10-5/25 | | 120hp | 3.39 | 5.30 | | 14.00 | | 51 | 72.00 | 107.44 |
| Cultivate | 6/15-6/30 | | 150hp | 1.21 | 1.76 | | | | | | 2.97 |
| Bloom spray | | | 85hp | 1.13 | 0.74 | | 22.03 | | | | 23.90 |
| Irrigate | | | | 25.92 | | | | | | 37.75 | 63.67 |
| Custom picking | | | | | | | | | | 150.00 | 150.00 |
| Haul | 8/1-8/20 | | | 10.50 | 5.81 | | | | | | 16.31 |
| Other eq., lime | | | | | 6.69 | | | | | 8.62 | 15.31 |
| Flail | 10/1-10/30 | | | 2.12 | 2.97 | | | | | | 5.09 |
| Subsoil | 10/5-11/10 | | 150hp | 1.21 | 2.13 | | | | | | 3.34 |
| Disc | | | 120hp | 1.54 | 3.13 | | | | | | 4.67 |
| Interest & fixed | | | | | | 99.72 | | | | 18.55 | |
| Total variable cost | | | | | | | | | | | 516.16 |
| TOTALS | | | | 56.07 | 45.69 | 99.72 | 74.61 | 58.67 | 12.75 | 286.92 | 634.43 |

CLOVER as a cover crop

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Plow (WHT) | 8/1-8/20 | 0.250 | 165hp | 2.72 | 6.23 | 6.43 | | | | | 8.95 |
| Springtooth | 8/5-8/25 | 0.080 | 165hp | 0.87 | 1.23 | 1.41 | | | | | 2.10 |
| Drill | 8/25-9/15 | 0.167 | 111hp | 1.81 | 3.53 | 3.37 | | | | 40.00 | 45.34 |
| Plow-in (C/W) | 4/10 or 5/1 | 0.250 | 165hp | 2.72 | 6.23 | 6.43 | | | | | 8.95 |
| Total variable cost | | | | | | | | | | | 65.34 |
| TOTALS | | | | 8.12 | 17.22 | 17.64 | 0.00 | 0.00 | 0.00 | 40.00 | 82.98 |

AUSTRIAN WINTER PEAS as a cover crop

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Plow (WHT) | 8/1-8/20 | 0.250 | 165hp | 2.72 | 6.23 | 6.43 | | | | | 8.95 |
| Springtooth(2X) | 8/5-8/25 | 0.080 | 165hp | 0.87 | 1.23 | 1.41 | | | | | 2.10 |
| Drill | 8/25-9/15 | 0.167 | 111hp | 1.81 | 3.53 | 3.37 | | | | 50.00 | 55.34 |
| Plow-in (C/W) | 5/1 or 5/25 | 0.250 | 165hp | 2.72 | 6.23 | 6.43 | | | | | 8.95 |
| Total variable cost | | | | | | | | | | | 75.34 |
| TOTALS | | | | 8.12 | 17.22 | 17.64 | 0.00 | 0.00 | 0.00 | 50.00 | 92.98 |

SPRING OATS

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Plow | 8/15-8/25 | 0.250 | 165hp | 2.72 | 6.23 | 6.43 | | | | | 8.95 |
| Disc (2X) | 8/25-9/5 | 0.500 | 165hp | 3.96 | 7.30 | 6.83 | | | | | 11.26 |
| Springtooth | 9/5-9/15 | 0.080 | 165hp | 0.87 | 1.23 | 1.41 | | | | | 2.10 |
| Drill/harrow | 9/15-9/30 | 0.167 | 111hp | 1.81 | 3.53 | 3.37 | | 250 | | 11.00 | 43.84 |
| Herbicide | | | | | | | 1.00 | | | 5.00 | 6.00 |
| Combine | 6/15-6/30 | 0.286 | 225hp | 2.25 | 15.16 | 9.40 | | | | | 17.41 |
| Haul grain | | | | 0.25 | 1.19 | 2.48 | | | | | 1.44 |
| Other | | | | 7.83 | 2.54 | 3.28 | | | | 7.00 | 17.37 |
| Interest | | | | | | | | | | 20.60 | |
| Total variable cost | | | | | | | | | | | 108.37 |
| TOTALS | | | | 19.69 | 37.18 | 33.20 | 1.00 | 27.50 | 0.00 | 43.60 | 162.17 |

CHRISTMAS TREES

| Operation | Year(s) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|
| Summer fallow | 0 | 111hp | 4.90 | 2.47 | 2.36 | | | | | 7.37 |
| Lime | 0 | | | | | | | | 7.80 | 7.80 |
| Seedings | 1,2 | | 9.10 | | | | | | 31.36 | 40.46 |
| Herbicide | 1,2,3,4,5 | | | | | 11.30 | | | 2.50 | 13.80 |
| Cultivate | 1,2,3 | | 4.73 | 2.38 | 2.27 | | | | | 7.11 |
| Mow | 4,5,6 | | 0.98 | 0.99 | 1.67 | | | | | 1.97 |
| Trim & shear | 2,3,4,5,6,7,8,9 | | 130.67 | | | | | | | 130.67 |
| Insect control | 6,7 | | | | | 2.20 | | | | 2.20 |
| Fertilize | 5 | | | | | | 150 | | 0.50 | 17.00 |
| Road maint | 1-9 | | | | | | | | 36.00 | 36.00 |
| Harvest | 6,7,8,9 | | | | | | | | 211.65 | 211.65 |
| Clean-up | 9 | | | | | | | | 70.55 | 70.55 |
| Gen. overhead | | | | | | | | | 60.00 | |
| Operating cap. | | | | | | | | | 23.10 | |
| Total variable cost | | | | | | | | | | 546.57 |
| TOTALS | | | 150.38 | 5.84 | 6.30 | 13.50 | 16.50 | 0.00 | 443.46 | 635.98 |

DRYLAND PASTURE - ESTABLISHMENT

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Plow | 8/15-8/25 | 0.250 | 165hp | 2.72 | 6.23 | 6.43 | | | | | 8.95 |
| Disc (2X) | 8/25-9/5 | 0.500 | 165hp | 3.96 | 7.30 | 6.83 | | | | | 11.26 |
| Cultipack (2X) | 8/25-9/10 | 0.300 | 165hp | 3.27 | 3.29 | 5.56 | | | | | 6.56 |
| Incorp. herb. | 9/5-9/15 | 0.330 | 165hp | 3.62 | 7.06 | 6.74 | 14.50 | | | | 25.18 |
| Plant | 9/15-9/30 | 0.167 | 111hp | 1.81 | 3.53 | 3.37 | | 250 | | 14.00 | 46.84 |
| Spring fertilize | | | | | | | | | 40 | 5.00 | 15.00 |
| Lime | | | | | | | | | | 78.00 | 78.00 |
| Clip | | 0.200 | 111hp | 3.27 | 3.29 | 5.56 | | | | | 6.56 |
| Other | | | | 3.50 | | | | | | 7.00 | 10.50 |
| Interest | | | | | | | | | | 15.00 | |
| Total variable cost | | | | | | | | | | | 208.85 |
| TOTALS | | | | 22.15 | 30.70 | 34.49 | 14.50 | 27.50 | 10.00 | 119.00 | 258.34 |

DRYLAND PASTURE - PRODUCTION

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fertilize | 10/1-10/30 | | | | | | | 70 | | 5.00 | 12.70 |
| Fertilize | 3/1-3/30 | | | | | | | | 40 | 5.00 | 15.00 |
| Swath (2X) | 7/1-8/15 | | | 3.60 | 12.04 | 3.84 | | | | | 15.64 |
| Baling, etc. | | | | | | | | | | 40.00 | 40.00 |
| Weeding, other | | 1.000 | 111hp | 7.83 | 2.54 | 3.28 | 1.00 | | | 7.00 | 18.37 |
| Interest | | | | | | | | | | 10.24 | |
| Total variable cost | | | | | | | | | | | 101.71 |
| TOTALS | | | | 11.43 | 14.58 | 7.12 | 1.00 | 7.70 | 10.00 | 67.24 | 119.07 |

IRRIGATED PASTURE - ESTABLISHMENT

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Plow | 8/15-8/25 | 0.250 | 165hp | 2.72 | 6.23 | 6.43 | | | | | 8.95 |
| Disc (3X) | 8/25-9/5 | 0.750 | 165hp | 5.94 | 10.95 | 10.25 | | | | | 16.89 |
| Cultipack (2X) | 8/25-9/10 | 0.300 | 165hp | 3.27 | 3.29 | 5.56 | | | | | 6.56 |
| Plant | 3/25-4/15 | 0.167 | 111hp | 1.81 | 3.53 | 3.37 | | 250 | | 14.00 | 46.84 |
| Fertilize | 3/1-3/30 | | | | | | | | 40 | 5.00 | 15.00 |
| Lime | | | | | | | | | | 78.00 | 78.00 |
| Irrigate (5X) | | 3.000 | | 13.50 | | | | | | 29.05 | 42.55 |
| Other | | | | 3.50 | | | | | | 7.00 | 10.50 |
| Interest | | | | | | | | | | 10.24 | |
| Total variable cost | | | | | | | | | | | 225.29 |
| TOTALS | | | | 30.74 | 24.00 | 25.61 | 0.00 | 27.50 | 10.00 | 143.29 | 251.14 |

IRRIGATED PASTURE - PRODUCTION

| Operation | Dates | Time (hr/ac) | Tract. | Labor ($) | Mach ($) | Fixed ($) | Herb. ($) | NPK (lbs) | Nitr. (lbs) | Other ($) | VARIABLE COSTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fertilize | 10/1-10/30 | | | | | | | 70 | | 5.00 | 12.70 |
| Fertilize | 3/1-3/30 | | | | | | | | 40 | 5.00 | 15.00 |
| Weeding, other | | 1.000 | 111hp | 7.83 | 2.54 | 3.28 | 1.00 | | | 7.00 | 18.37 |
| Irrigate (6X) | | 5.000 | | 22.50 | | | | | | 37.30 | 59.80 |
| Interest | | | | | | | | | | 10.24 | |
| Total variable cost | | | | | | | | | | | 105.87 |
| TOTALS | | | | 30.33 | 2.54 | 3.28 | 1.00 | 7.70 | 10.00 | 64.54 | 119.39 |

## APPENDIX C: Solutions to GAMS farm LP runs

The following pages contain the solutions to the individual linear programming model runs, for each of the five representative farms. Below is the key of rotation name symbols.

| | |
|---|---|
| W1 | Wheat (no-till) |
| W0X | Wheat under fall fertilizer ban |
| R0 | Annual ryegrass (conventional tillage) |
| R1 | Annual ryegrass (no-till) |
| RX | Annual ryegrass under fall fertilizer ban |
| R50 | Annual ryegrass (50% fertilizer applied) |
| CB | Corn-snap beans |
| CB85 | Corn-snap beans (85% fertilizer applied) |
| CB75 | Corn-snap beans (75% fertilizer applied) |
| CB50 | Corn-snap beans (50% fertilizer applied) |
| WR01 | Wheat-annual ryegrass (no-till) |
| CBW | Corn-snap beans-wheat with winter clover cover |
| CBW85 | Corn-snap beans-wheat with winter clover cover (85% fertilizer applied) |
| CBW75 | Corn-snap beans-wheat with winter clover cover (75% fertilizer applied) |
| G | Perennial ryegrass (5-year rotation) |
| GX | Perennial ryegrass under fall fertilizer ban |
| G75 | Perennial ryegrass (75% fertilizer applied) |
| F | Tall fescue (5-year rotation) |
| FX | Tall fescue under fall fertilizer ban |
| GW | Perennial ryegrass (5-yr) - wheat |
| FW | Tall fescue (5-yr) - wheat |
| H | Mixed hay (7-year) |
| HI | Mixed hay, irrigated (7-year) |
| P | Pasture (7-year) |
| S | Christmas trees (9-year rotation) |
| U | Unimproved pasture |

BOTTOMLANDS - WELL DRAINED (450 ACRES)

| Case | CHEHALIS W1 | WOX | R1 | CB | CBB5 | WR01 | CBW | CBWB5 | CBW75 | G | GX | F | FX | GW | FW | HI | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unrestricted | 49.5 | | | 83.7 | | | 29.7 | | | 18.0 | | 10.8 | | | | | 450.0 |
| + Prk < 15 | 30.3 | | | 64.5 | | | 48.9 | | | 18.0 | | 10.8 | | | | | 450.0 |
| + Prk < 12.5 | | 18.6 | | 52.8 | | | 48.7 | | 11.9 | 18.0 | | 10.8 | | | | | 450.0 |
| + Prk < 10 | | 18.6 | | 52.8 | | | 24.0 | | 36.6 | 18.0 | | 10.8 | | | | | 450.0 |
| + Prk < 7.5 | | 18.5 | | 52.1 | | | | | 61.1 | 18.0 | | 10.8 | | | | | 450.0 |
| + Prk < 5 | | 14.7 | | 30.5 | | | | | 76.8 | 18.0 | | 10.8 | | | | | 450.0 |
| + Prk < 2.5 | | 10.8 | | 8.8 | | | | | 92.5 | 18.0 | | 10.8 | | | | | 450.0 |
| + Prk < 1 | | 2.5 | 6.8 | | | | | | 98.9 | 18.0 | | | 10.8 | | | | 450.0 |
| Runoff taxes | | | | | | | | | | | | | | | | | |
| - (N-loss+NO3) = 4 | 49.5 | | | 83.7 | | | 29.7 | | | 18.0 | | 10.8 | | | | | 450.0 |
| - (N-loss+NO3) = 8 | 49.5 | | | 83.7 | | | 29.7 | | | 18.0 | | 10.8 | | | | | 450.0 |
| - (N-loss+NO3) = 12 | 38.7 | | | 83.7 | | | 29.7 | | | 18.0 | | | | | 10.8 | | 450.0 |
| - Percolated-N = 1 | 49.5 | | | 83.7 | | | 29.7 | | | 18.0 | | 10.8 | | | | | 450.0 |
| - Percolated-N = 2 | 49.5 | | | 83.7 | | | 29.7 | | | 18.0 | | 10.8 | | | | | 450.0 |
| - Percolated-N = 4 | | 18.6 | | 52.8 | | | | | 60.6 | 18.0 | | 10.8 | | | | | 450.0 |
| - Percolated-N = 6 | | | 9.3 | | | | | | 98.9 | 18.0 | | | 10.8 | | | | 450.0 |
| - Percolated-N = 8 | | | 9.3 | | | | | | 98.9 | 18.0 | | | 10.8 | | | | 450.0 |
| - Percolated-N = 12 | | | 9.3 | | | | | | 98.9 | | 18.0 | | 10.8 | | | | 450.0 |
| - Surf & GW tax = 1 | 49.5 | | | 83.7 | | | 29.7 | | | 18.0 | | 10.8 | | | | | 450.0 |
| - Surf & GW tax = 2 | 49.5 | | | 83.7 | | | 29.7 | | | 18.0 | | 10.8 | | | | | 450.0 |
| - Surf & GW tax = 4 | | 18.6 | | 52.8 | | | | | 60.6 | 18.0 | | 10.8 | | | | | 450.0 |
| - Surf & GW tax = 6 | | | 9.3 | | | | | | 98.9 | 18.0 | | | 10.8 | | | | 450.0 |
| - Surf & GW tax = 8 | | | | | | | | | 98.9 | 18.0 | | | 10.8 | | | 1.3 | 450.0 |
| - Surf & GW tax = 12 | | | | | | | | | 98.9 | | 18.0 | | 10.8 | | | 1.3 | 450.0 |
| Input taxes | | | | | | | | | | | | | | | | | |
| - + 50% on Nitrogen | 49.5 | | | 83.6 | | | 29.7 | | | | 18.0 | | 10.8 | | | | 449.9 |
| - +100% on Nitrogen | 49.5 | | | 83.6 | | | 29.7 | | | | 18.0 | | 10.8 | | | | 449.9 |
| Runoff standards | | | | | | | | | | | | | | | | | |
| - Prkn = 30 | | | | 89.2 | | 13.1 | 24.3 | | | | | | | 18.0 | 10.8 | | 450.0 |
| - Prkn = 20 | | | | | 52.8 | | 60.6 | | | 10.2 | | | | 7.8 | 10.8 | | 450.0 |
| - Prkn = 15 | | | | | | | | 98.9 | | 18.0 | | 1.5 | | | 9.3 | | 450.0 |
| - Prkn = 10 | | | | | | | | | 98.9 | 18.0 | | 1.5 | | | 9.3 | | 450.0 |
| - Prkn = 6 | | | 9.3 | | | | | | 98.9 | 18.0 | | 10.8 | | | | | 450.0 |
| - N-loss + NO3 = 20 | 49.5 | | | 83.7 | | | 29.7 | | | 18.0 | | 10.8 | | | | | 450.0 |
| - N-loss + NO3 = 10 | 49.5 | | | 83.7 | | | 29.7 | | | 18.0 | | 10.8 | | | | | 450.0 |
| - 30/20 | | | | 89.2 | | 13.1 | 24.3 | | | | | | | 18.0 | 10.8 | | 450.0 |
| - 20/20 | | | | | 52.8 | | 60.6 | | | 10.2 | | | | 7.8 | 10.8 | | 450.0 |
| - 15/10 | | | | | | | | 98.9 | | 18.0 | | 1.5 | | | 9.3 | | 450.0 |
| Required no-tillage | 130.3 | | | 87.8 | | | | | | 18.0 | | 10.8 | | | | | 450.0 |
| Fall fertilizer ban | | 130.3 | | 87.8 | | | | | | | 18.0 | | 10.8 | | | | 450.0 |

BOTTOMLANDS - POORLY DRAINED (200 ACRES)

| Case | WAPATO R1 | RX | R50 | G | F | H1 | TOTAL |
|---|---|---|---|---|---|---|---|
| Unrestricted | 136.0 | | | 8.0 | 4.8 | | 200.0 |
| + NO3 < 10 | 105.3 | 30.7 | | 8.0 | 4.8 | | 200.0 |
| + NO3 < 7.5 | | 109.1 | | 8.0 | 4.8 | 3.8 | 200.0 |
| + NO3 < 5 | | 66.0 | | 8.0 | 4.8 | 10.0 | 200.0 |
| + NO3 < 2.5 | | 22.8 | | 8.0 | 4.8 | 16.2 | 200.0 |
| + NO3 < 1.5 | | 5.6 | | 8.0 | 4.8 | 18.6 | 200.0 |
| + NO3 < 1.25 | | 1.3 | | 8.0 | 4.8 | 19.2 | 200.0 |
| + NO3 < 1 | | | | 4.9 | | 25.0 | 200.0 |
| Runoff taxes | | | | | | | |
| - (N-loss+NO3) = 1 | 136.0 | | | 8.0 | 4.8 | | 200.0 |
| - (N-loss+NO3) = 2 | 136.0 | | | 8.0 | 4.8 | | 200.0 |
| - (N-loss+NO3) = 4 | 136.0 | | | 8.0 | 4.8 | | 200.0 |
| - (N-loss+NO3) = 6 | 136.0 | | | 8.0 | 4.8 | | 200.0 |
| - (N-loss+NO3) = 8 | | 136.0 | | 8.0 | 4.8 | | 200.0 |
| - (N-loss+NO3) = 12 | | 136.0 | | 8.0 | 4.8 | | 200.0 |
| - Percolated-N = 4 | 136.0 | | | 8.0 | 4.8 | | 200.0 |
| - Percolated-N = 8 | 136.0 | | | 8.0 | 4.8 | | 200.0 |
| - Percolated-N = 12 | 160.0 | | | 8.0 | | | 200.0 |
| - Surf & GW tax = 1 | 136.0 | | | 8.0 | 4.8 | | 200.0 |
| - Surf & GW tax = 2 | 136.0 | | | 8.0 | 4.8 | | 200.0 |
| - Surf & GW tax = 4 | 136.0 | | | 8.0 | 4.8 | | 200.0 |
| - Surf & GW tax = 6 | | 136.0 | | 8.0 | 4.8 | | 200.0 |
| - Surf & GW tax = 8 | | 136.0 | | 8.0 | 4.8 | | 200.0 |
| - Surf & GW tax = 12 | | 136.0 | | 8.0 | 4.8 | | 200.0 |
| Input taxes | | | | | | | |
| - + 50% on Nitrogen | 136.0 | | | 8.0 | 4.8 | | 200.0 |
| - +100% on Nitrogen | | 136.0 | | 8.0 | 4.8 | | 200.0 |
| Runoff standards | | | | | | | |
| - Prkn = 30 | 136.0 | | | 8.0 | 4.8 | | 200.0 |
| - Prkn = 15 | 136.0 | | | 8.0 | 4.8 | | 200.0 |
| - N-loss + NO3 = 20 | 136.0 | | | 8.0 | 4.8 | | 200.0 |
| - N-loss + NO3 = 15 | 136.0 | | | 8.0 | 4.8 | | 200.0 |
| - N-loss + NO3 = 10 | | | 136.0 | 8.0 | 4.8 | | 200.0 |
| - N-loss + NO3 = 5 | | | | 8.0 | 4.8 | 19.4 | 200.0 |
| - 30/20 | 136.0 | | | 8.0 | 4.8 | | 200.0 |
| - 15/10 | | | 136.0 | 8.0 | 4.8 | | 200.0 |
| Required no-tillage | 136.0 | | | 8.0 | 4.8 | | 200.0 |
| Fall fertilizer ban | | 200.0 | | | | | 200.0 |

TERRACE LANDS - WELL DRAINED (500 ACRES) - CONTINUED

| Case | WOODBURN-15% WR01 | F | FI | FW | H | 1% TOTAL | 6% TOTAL | 10% TOTAL | 15% TOTAL | ALL TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| Unrestricted | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| + 10 / 7.5 / 7.5 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| + 4 / 4 / 4 | | | | 2.5 | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| + 5 / 3 / 3 | | | | 1.6 | 0.7 | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| + 3 / 3 / 3 | | | | | 2.1 | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| + 3 / 2 / 2 | | | | | 2.1 | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| Runoff taxes | | | | | | | | | | |
| - (N-loss+NO3) = 1 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - (N-loss+NO3) = 2 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - (N-loss+NO3) = 4 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - (N-loss+NO3) = 6 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - (N-loss+NO3) = 8 | | | 3.0 | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - (N-loss+NO3) = 12 | | | 3.0 | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - Percolated-N = 1 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - Percolated-N = 2 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - Percolated-N = 4 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - Percolated-N = 6 | 7.5 | | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - Percolated-N = 8 | 7.5 | | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - Percolated-N = 12 | 7.5 | | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - Surf & GW tax = 1 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - Surf & GW tax = 2 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - Surf & GW tax = 4 | | | 3.0 | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - Surf & GW tax = 6 | | | 3.0 | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - Surf & GW tax = 8 | | | 3.0 | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - Surf & GW tax = 12 | | | 3.0 | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - Erosion = 2.50 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - Erosion = 5.00 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| Input taxes | | | | | | | | | | |
| - + 50% on Nitrogen | | | 3.0 | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - +100% on Nitrogen | | | 3.0 | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| Runoff standards | | | | | | | | | | |
| - Prkn = 30 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - Prkn = 15 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - Prkn = 10 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - Prkn = 5 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - N-loss + NO3 = 20 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - N-loss + NO3 = 10 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - N-loss + NO3 = 5 | | | | | | 345.1 | 80.0 | 32.0 | 0.0 | 457.1 |
| - Erosion = 5 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - 30/20 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - 15/10 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - 15/10/ 5 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| - 10/5 | | | | | | 373.0 | 52.1 | 32.0 | 0.0 | 457.1 |
| - Prkn = 5, Er = 5 | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| Required no-tillage | | 3.0 | | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |
| Fall fertilizer ban | | | 3.0 | | | 373.0 | 80.0 | 32.0 | 15.0 | 500.0 |

TERRACE LANDS - WELL DRAINED (500 ACRES) - CONTINUED

| Case | WOODBURN-6% | | | | | | | | | | | | WOODBURN-10% | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | W1 | WR01 | CB85 | CB50 | CBW | G | FX | FW | GW | H | HI | P | WR01 | F | FX | GI | FW | GW | H |
| Unrestricted | | | 40.0 | | | | | | | | | | | 6.4 | | | | | |
| + 10 / 7.5 / 7.5 | | | | | | 16.0 | | | | | | | | 6.4 | | | | | |
| + 4 / 4 / 4 | | | | | | | | 4.2 | 5.8 | | 2.9 | | | | | | 5.3 | | |
| + 5 / 3 / 3 | | | | | | | | | | | 11.4 | | | | | | 5.3 | | |
| + 3 / 3 / 3 | | | | 16.5 | | | | | | | 6.7 | | | | | | 5.3 | | |
| + 3 / 2 / 2 | | | | | | | | | | 11.4 | | | | | | | | | 4.6 |
| Runoff taxes | | | | | | | | | | | | | | | | | | | |
| - (N-loss+NO3) = 1 | | | | | | 16.0 | | | | | | | | 6.4 | | | | | |
| - (N-loss+NO3) = 2 | | | | | | 16.0 | | | | | | | | 6.4 | | | | | |
| - (N-loss+NO3) = 4 | | | | | | 16.0 | | | | | | | | 6.4 | | | | | |
| - (N-loss+NO3) = 6 | | | | | | 16.0 | | | | | | | | 6.4 | | | | | |
| - (N-loss+NO3) = 8 | | | | | | 16.0 | | | | | | | | | | | 5.3 | | |
| - (N-loss+NO3) = 12 | | | | | | | | 3.7 | 9.7 | | | | | | | | 5.3 | | |
| - Percolated-N = 1 | | | 40.0 | | | | | | | | | | | 6.4 | | | | | |
| - Percolated-N = 2 | | | 40.0 | | | | | | | | | | | 6.4 | | | | | |
| - Percolated-N = 4 | | | 40.0 | | | | | | | | | | | 6.4 | | | | | |
| - Percolated-N = 6 | | | 40.0 | | | | | | | | | | 16.0 | | | | | | |
| - Percolated-N = 8 | | | 40.0 | | | | | | | | | | 16.0 | | | | | | |
| - Percolated-N = 12 | | 1.5 | 38.5 | | | | | | | | | | 16.0 | | | | | | |
| - Surf & GW tax = 1 | | | | | | 16.0 | | | | | | | | 6.4 | | | | | |
| - Surf & GW tax = 2 | | | | | | 16.0 | | | | | | | | 6.4 | | | | | |
| - Surf & GW tax = 4 | | | | | | 16.0 | | | | | | | | 6.4 | | | | | |
| - Surf & GW tax = 6 | | | | | | 16.0 | | | | | | | | 6.4 | | | | | |
| - Surf & GW tax = 8 | | | | | | 16.0 | | | | | | | | | 6.4 | | | | |
| - Surf & GW tax = 12 | | | | | | 7.0 | 9.0 | | | | | | | | | | | 5.3 | |
| - Erosion = 2.50 | | | | | | 16.0 | | | | | | | | 6.4 | | | | | |
| - Erosion = 5.00 | | | | | | 16.0 | | | | | | | | 6.4 | | | | | |
| Input taxes | | | | | | | | | | | | | | | | | | | |
| - + 50% on Nitrogen | | | 40.0 | | | | | | | | | | | | 6.4 | | | | |
| - +100% on Nitrogen | | | 40.0 | | | | | | | | | | | | | 6.4 | | | |
| Runoff standards | | | | | | | | | | | | | | | | | | | |
| - Prkn = 30 | | | 40.0 | | | | | | | | | | | 6.4 | | | | | |
| - Prkn = 15 | | | 40.0 | | | | | | | | | | | 6.4 | | | | | |
| - Prkn = 10 | | | 40.0 | | | | | | | | | | | 6.4 | | | | | |
| - Prkn = 5 | | | | | 26.7 | | | | | | | | | 6.4 | | | | | |
| - N-loss + NO3 = 20 | | | | | | 16.0 | | | | | | | | 6.4 | | | | | |
| - N-loss + NO3 = 10 | | | | | | 16.0 | | | | | | | | 6.4 | | | | | |
| - N-loss + NO3 = 5 | | | | | | | | | | | | 11.4 | | | | | | 5.3 | |
| - Erosion = 5 | | | | | | 16.0 | | | | | | | | 6.4 | | | | | |
| - 30/20 | | | | | | 16.0 | | | | | | | | 6.4 | | | | | |
| - 15/10 | | | | | | 16.0 | | | | | | | | 6.4 | | | | | |
| - 15/10/ 5 | | | | | | 16.0 | | | | | | | | 6.4 | | | | | |
| - 10/5 | | | | | | | | | | | | 7.4 | | | | | | 5.3 | |
| - Prkn = 5, Er = 5 | | | | | | 16.0 | | | | | | | | 6.4 | | | | | |
| Required no-tillage | 80.0 | | | | | | | | | | | | | 6.4 | | | | | |
| Fall fertilizer ban | | | 40.0 | | | | | | | | | | | | | 6.4 | | | |

TERRACE LANDS - WELL DRAINED (500 ACRES)

WOODBURN-1%

| Case | W1 | WI | WR01 | CB | CB85 | CB75 | CB50 | CBW | CBW85 | G | GX | F | FX | GW | FW | HI | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unrestricted | | | 69.4 | | 60.6 | | | | | 20.0 | | 2.6 | | | | | |
| + 10 / 7.5 / 7.5 | | | 68.6 | | 100.2 | | | 0.8 | | 4.0 | | 2.6 | | | | | |
| + 4 / 4 / 4 | | | 16.1 | | 84.7 | | | 1.2 | 27.5 | | | | | 14.2 | | | |
| + 5 / 3 / 3 | | | | | 105.7 | | | 3.8 | | | | | | 20.0 | 5.0 | | |
| + 3 / 3 / 3 | | | | | 27.5 | | 43.4 | | 25.9 | | | | 6.7 | 20.0 | | | |
| + 3 / 2 / 2 | | | | | | | 95.7 | | | | 1.1 | | 12.0 | 18.9 | | 0.4 | |
| Runoff taxes | | | | | | | | | | | | | | | | | |
| - (N-loss+NO3) = 1 | | | 69.4 | | 100.6 | | | | | 4.0 | | 2.6 | | | | | |
| - (N-loss+NO3) = 2 | | | 69.4 | | 100.6 | | | | | 4.0 | | 2.6 | | | | | |
| - (N-loss+NO3) = 4 | | | 43.8 | | 87.8 | | | 25.6 | | 4.0 | | 2.6 | | | | | |
| - (N-loss+NO3) = 6 | | | 43.8 | | 87.8 | | | 25.6 | | 4.0 | | 2.6 | | | | | |
| - (N-loss+NO3) = 8 | | | 40.4 | | 86.4 | | | 27.0 | | 4.0 | | 3.7 | | | | | |
| - (N-loss+NO3) = 12 | | | 25.4 | | 80.1 | | | 33.3 | | | | | | 10.3 | | | |
| - Percolated-N = 1 | | | 69.4 | | 60.6 | | | | | 20.0 | | 2.6 | | | | | |
| - Percolated-N = 2 | | | 69.4 | | 60.6 | | | | | 20.0 | | 2.6 | | | | | |
| - Percolated-N = 4 | | | 43.8 | | 47.8 | | | | 25.6 | 20.0 | | 2.6 | | | | | |
| - Percolated-N = 6 | | | 20.3 | | 47.8 | | | | 25.6 | 20.0 | | 12.0 | | | | | |
| - Percolated-N = 8 | | | 2.8 | | 12.8 | | | | 60.6 | 20.0 | | 12.0 | | | | | |
| - Percolated-N = 12 | | | | | | | | | 71.0 | 20.0 | | | 12.0 | | | | |
| - Surf & GW tax = 1 | | | 69.4 | | 100.6 | | | | | 4.0 | | 2.6 | | | | | |
| - Surf & GW tax = 2 | | | 69.4 | | 100.6 | | | | | 4.0 | | 2.6 | | | | | |
| - Surf & GW tax = 4 | | | 43.8 | | 87.8 | | | | 25.6 | 4.0 | | 2.6 | | | | | |
| - Surf & GW tax = 6 | | | 43.8 | | 87.8 | | | | 25.6 | 4.0 | | 2.6 | | | | | |
| - Surf & GW tax = 8 | | | 26.3 | | 52.8 | | | | 60.6 | 4.0 | | 2.6 | | | | | |
| - Surf & GW tax = 12 | | | 19.0 | | | | | | 98.9 | 7.7 | | | | | | | |
| - Erosion = 2.50 | | | 69.4 | 100.6 | | | | | | 4.0 | | 2.6 | | | | | |
| - Erosion = 5.00 | | | 69.4 | 100.6 | | | | | | 4.0 | | 2.6 | | | | | |
| Input taxes | | | | | | | | | | | | | | | | | |
| - + 50% on Nitrogen | | | 69.4 | | 60.6 | | | | | 20.0 | | | 2.6 | | | | |
| - +100% on Nitrogen | | | 69.4 | | 60.6 | | | | | | 13.6 | | 9.0 | | | | |
| Runoff standards | | | | | | | | | | | | | | | | | |
| - Prkn = 30 | | | 69.4 | | 60.6 | | | | | 20.0 | | 2.6 | | | | | |
| - Prkn = 15 | | | 69.4 | | 60.6 | | | | | 20.0 | | 2.6 | | | | | |
| - Prkn = 10 | | | 69.4 | | 60.6 | | | | | 20.0 | | 2.6 | | | | | |
| - Prkn = 5 | | | 43.3 | | | 86.7 | | | | 20.0 | | 2.6 | | | | | |
| - N-loss + NO3 = 20 | | | 69.4 | | 100.6 | | | | | 4.0 | | 2.6 | | | | | |
| - N-loss + NO3 = 10 | | | 69.4 | | 100.6 | | | | | 4.0 | | 2.6 | | | | | |
| - N-loss + NO3 = 5 | | | | | | | | | | | | | | 14.7 | 12.0 | | 26.4 |
| - Erosion = 5 | | | 69.4 | | 100.6 | | | | | 4.0 | | 2.6 | | | | | |
| - 30/20 | | | 69.4 | | 100.6 | | | | | 4.0 | | 2.6 | | | | | |
| - 15/10 | | | 69.4 | | 100.6 | | | | | 4.0 | | 2.6 | | | | | |
| - 15/10/ 5 | | | 69.4 | | 100.6 | | | | | 4.0 | | 2.6 | | | | | |
| - 10/5 | | | | | | | | | | | | | | 14.7 | 12.0 | | 30.4 |
| - Prkn = 5, Er = 5 | | | 43.8 | | | 87.8 | | | 25.6 | 4.0 | | 2.6 | | | | | |
| Required no-tillage | 108.8 | | | | 75.6 | | | | | 20.0 | | 2.6 | | | | | |
| Fall fertilizer ban | | 188.8 | | | 35.6 | | | | | | 13.6 | | 9.0 | | | | |

TERRACE LANDS - POORLY DRAINED (1000 ACRES)

| | AMITY | | | | | | | | | DAYTON | | | | | | | | AMITY | DAYTON | ALL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Case | CB | CB50 | G | GI | G75 | F | FI | GW | HI | R0 | R1 | RI | R50 | G | F | FI | U | TOTAL | TOTAL | TOTAL |
| Unrestricted | 13.0 | | 40.0 | | | 6.8 | | | | | 740.0 | | | | | | | 260.0 | 740.0 | 1000.0 |
| + NO3 < 12.5 | 13.0 | | 40.0 | | | 6.8 | | | | | 740.0 | | | | | | | 260.0 | 740.0 | 1000.0 |
| + NO3 < 10 | 13.0 | | | | | | | 39.0 | | 141.0 | 474.0 | | | 1.0 | 24.0 | | | 260.0 | 740.0 | 1000.0 |
| + NO3 < 7.5 | 13.0 | | | | | | | 39.0 | | 245.5 | 196.6 | | | 1.0 | 24.0 | | 17.3 | 260.0 | 740.0 | 1000.0 |
| + NO3 < 5 | 13.0 | | | | | | | 39.0 | | 245.5 | 9.7 | | | 1.0 | 24.0 | | 36.0 | 260.0 | 740.0 | 1000.0 |
| + NO3 < 2.5 | 13.0 | | | | | | | 39.0 | | 41.2 | | | | 1.0 | 24.0 | | 57.4 | 260.0 | 740.0 | 1000.0 |
| + NO3 < 1.75 | | | | | | | | 34.8 | 7.3 | | | | | 5.2 | | | 71.4 | 260.0 | 740.0 | 1000.0 |
| Runoff taxes | | | | | | | | | | | | | | | | | | | | |
| - (N-loss+NO3) = 1 | 13.0 | | 40.0 | | | 6.8 | | | | | 740.0 | | | | | | | 260.0 | 740.0 | 1000.0 |
| - (N-loss+NO3) = 2 | 13.0 | | 40.0 | | | 6.8 | | | | | 654.0 | | | | 17.2 | | | 260.0 | 740.0 | 1000.0 |
| - (N-loss+NO3) = 4 | 13.0 | | 40.0 | | | 6.8 | | | | | 654.0 | | | | 17.2 | | | 260.0 | 740.0 | 1000.0 |
| - (N-loss+NO3) = 6 | 13.0 | | | | | | | 39.0 | | | 615.0 | | | 1.0 | 24.0 | | | 260.0 | 740.0 | 1000.0 |
| - (N-loss+NO3) = 8 | 13.0 | | | | | | | 39.0 | | | 615.0 | | | 1.0 | 24.0 | | | 260.0 | 740.0 | 1000.0 |
| - (N-loss+NO3) = 12 | 13.0 | | | | | | | 39.0 | | | | | | 1.0 | 24.0 | | 61.5 | 260.0 | 740.0 | 1000.0 |
| - Percolated-N = 1 | | | 40.0 | | | 12.0 | | | | | 740.0 | | | | | | | 260.0 | 740.0 | 1000.0 |
| - Percolated-N = 2 | | | 40.0 | | | 12.0 | | | | | 740.0 | | | | | | | 260.0 | 740.0 | 1000.0 |
| - Percolated-N = 4 | | | 40.0 | | | | 12.0 | | | | 740.0 | | | | | | | 260.0 | 740.0 | 1000.0 |
| - Percolated-N = 6 | | | | 40.0 | | | 12.0 | | | | 740.0 | | | | | | | 260.0 | 740.0 | 1000.0 |
| - Percolated-N = 8 | | | | 40.0 | | | 12.0 | | | | 740.0 | | | | | | | 260.0 | 740.0 | 1000.0 |
| - Percolated-N = 12 | | | | 40.0 | | | 12.0 | | | | 740.0 | | | | | | | 260.0 | 740.0 | 1000.0 |
| - Surf & GW tax = 1 | | | 40.0 | | | 12.0 | | | | | 740.0 | | | | | | | 260.0 | 740.0 | 1000.0 |
| - Surf & GW tax = 2 | | | | 40.0 | | | 12.0 | | | | 680.0 | | | | | 12.0 | | 260.0 | 740.0 | 1000.0 |
| - Surf & GW tax = 4 | | | | 40.0 | | | 12.0 | | | | 680.0 | | | | | 12.0 | | 260.0 | 740.0 | 1000.0 |
| - Surf & GW tax = 6 | | | | 40.0 | | | 12.0 | | | | 680.0 | | | | | 12.0 | | 260.0 | 740.0 | 1000.0 |
| - Surf & GW tax = 8 | | | | 40.0 | | | 12.0 | | | | 680.0 | | | | | 12.0 | | 260.0 | 740.0 | 1000.0 |
| - Surf & GW tax = 12 | | | | 40.0 | | | 12.0 | | | | | | | | | 12.0 | 68.0 | 260.0 | 740.0 | 1000.0 |
| Input taxes | | | | | | | | | | | | | | | | | | | | |
| - + 50% on Nitrogen | | | | 40.0 | | | 12.0 | | | | 740.0 | | | | | | | 260.0 | 740.0 | 1000.0 |
| - +100% on Nitrogen | | | | 40.0 | | | 12.0 | | | | 680.0 | | | | | 12.0 | | 260.0 | 740.0 | 1000.0 |
| Runoff standards | | | | | | | | | | | | | | | | | | | | |
| - Prkn = 30 | 13.0 | | 40.0 | | | 6.8 | | | | | 740.0 | | | | | | | 260.0 | 740.0 | 1000.0 |
| - Prkn = 15 | | | 40.0 | | | 12.0 | | | | | 740.0 | | | | | | | 260.0 | 740.0 | 1000.0 |
| - N-loss + NO3 = 20 | 13.0 | | 40.0 | | | 6.8 | | | | | 740.0 | | | | | | | 260.0 | 740.0 | 1000.0 |
| - N-loss + NO3 = 10 | | 13.0 | | | | | | 39.0 | | | | | 615.0 | 1.0 | 24.0 | | | 260.0 | 740.0 | 1000.0 |
| - N-loss + NO3 = 5 | | | | | 40.0 | | 12.0 | | | | | | | | 12.0 | | 68.0 | 260.0 | 740.0 | 1000.0 |
| - 30/20 | 13.0 | | 40.0 | | | 6.8 | | | | | 740.0 | | | | | | | 260.0 | 740.0 | 1000.0 |
| - 15/10 | | 13.0 | | | | | | 39.0 | | | | | 615.0 | 1.0 | 24.0 | | | 260.0 | 740.0 | 1000.0 |
| Required no-tillage | 13.0 | | 40.0 | | | 6.8 | | | | | 740.0 | | | | | | | 260.0 | 740.0 | 1000.0 |
| Fall fertilizer ban | 13.0 | | | 40.0 | | | 6.8 | | | | | 740.0 | | | | | | 260.0 | 740.0 | 1000.0 |

FOOTHILLS - WELL DRAINED (400 ACRES)

| Case | JORY-5% | | | | | | | | JORY-10% | | | | | | | | JORY-15% | | 5% | 10% | 15% | ALL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WI | WR01 | GX | FX | GW | FW | S | U | WI | WR01 | GX | FX | GW | FW | S | U | S | U | TOTAL | TOTAL | TOTAL | TOTAL |
| Unrestricted | | 90.0 | 2.6 | | | | | | | | 13.4 | | | | 6.1 | | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| + 20 / 7.5 / 7.5 | | 32.5 | 16.0 | 9.6 | | | | | | 15.1 | | | | | 9.8 | | 4.2 | 3.7 | 193.0 | 128.0 | 79.0 | 400.0 |
| + 17.5 / 5 / 5 | | 31.1 | 16.0 | 9.6 | | | 0.3 | | | | | | | | 5.8 | 7.0 | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| + 15 / 5 / 5 | | 15.2 | 16.0 | 9.6 | | | 3.5 | | | | | | | | 2.6 | 10.2 | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| + 12.5 / 5 / 5 | | | 11.1 | | | | 13.8 | | | | 4.9 | 9.6 | | | | 5.5 | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| + 10 / 5 / 5 | | | 16.0 | 6.3 | | | 8.1 | | | | | 3.3 | | | | 11.2 | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| + 7.5 / 3 / 3 | | | 16.0 | 9.6 | | | 2.5 | 4.0 | | | | | | | | 12.8 | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| Runoff taxes | | | | | | | | | | | | | | | | | | | | | | |
| - (N-loss+NO3) = 1 | | 90.0 | 2.6 | | | | | | | | 13.4 | | | | 6.1 | | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| - (N-loss+NO3) = 2 | | 66.0 | 12.2 | | | | | | | | 3.8 | 9.6 | | | 6.1 | | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| - (N-loss+NO3) = 4 | | 66.0 | 12.2 | | | | | | | | 3.8 | 9.6 | | | 6.1 | | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| - (N-loss+NO3) = 6 | | 59.9 | | | 12.2 | | | | | | 3.8 | 9.6 | | | 6.1 | | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| - (N-loss+NO3) = 8 | | | | 9.6 | 16.0 | | 4.9 | | | | | | | | 9.1 | 3.7 | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| - (N-loss+NO3) = 12 | | | | 9.6 | 16.0 | | 4.9 | | | | | | | | 9.1 | 3.7 | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| - Percolated-N = 1 | | 66.0 | 12.2 | | | | | | | | 3.8 | 9.6 | | | 6.1 | | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| - Percolated-N = 2 | | 66.0 | 12.2 | | | | | | | | 3.8 | 9.6 | | | 6.1 | | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| - Percolated-N = 4 | | | 16.0 | 9.6 | | | 6.5 | | | | | | | | 7.5 | 5.3 | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| - Percolated-N = 6 | | | 16.0 | 9.6 | | | 6.5 | | | | | | | | 7.5 | 5.3 | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| - Percolated-N = 8 | | | 16.0 | 9.6 | | | 6.5 | | | | | | | | 7.5 | 5.3 | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| - Percolated-N = 12 | | | 16.0 | 9.6 | | | 6.5 | | | | | | | | 7.5 | 5.3 | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| - Surf & GW tax = 1 | | 66.0 | 12.2 | | | | | | | | 3.8 | 9.6 | | | 6.1 | | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| - Surf & GW tax = 2 | | 66.0 | 12.2 | | | | | | | | 3.8 | 9.6 | | | 6.1 | | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| - Surf & GW tax = 4 | | | 16.0 | 9.6 | | | 6.5 | | | | | | | | 7.5 | 5.3 | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| - Surf & GW tax = 6 | | | 16.0 | 9.6 | | | 6.5 | | | | | | | | 7.5 | 5.3 | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| - Surf & GW tax = 8 | | | 16.0 | 9.6 | | | 6.5 | | | | | | | | 7.5 | 5.3 | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| - Surf & GW tax = 12 | | | 16.0 | 9.6 | | | 6.5 | | | | | | | | 7.5 | 5.3 | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| - Erosion = 2.50 | | 90.0 | 2.6 | | | | | | | | 13.4 | | | | 6.1 | | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| - Erosion = 5.00 | | 90.0 | 2.6 | | | | | | | | 13.4 | | | | 6.1 | | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| Input taxes | | | | | | | | | | | | | | | | | | | | | | |
| - + 50% on Nitrogen | | 66.0 | 12.2 | | | | | | | | 3.8 | 9.6 | | | 6.1 | | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| - +100% on Nitrogen | | 66.0 | 12.2 | | | | | | | | 3.8 | 9.6 | | | 6.1 | | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| Runoff standards | | | | | | | | | | | | | | | | | | | | | | |
| - Prkn = 30 | | | | | | 9.6 | 10.8 | 2.7 | | | | | 16.0 | | 3.2 | | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| - Prkn = 20 | | | | | 16.0 | 9.6 | | 3.9 | | | | | | | | 12.8 | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| - Prkn = 15 | | | | | 16.0 | 9.6 | | 3.9 | | | | | | | | 12.8 | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| - Prkn = 10 | | | 16.0 | 9.6 | | | | 6.5 | | | | | | | | 12.8 | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| - Prkn = 5 | | | | | | | | 19.3 | | | | | | | | 12.8 | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| - N-loss + NO3 = 20 | | 90.0 | 2.6 | | | | | | | | 13.4 | | | | 6.1 | | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| - N-loss + NO3 = 10 | | | | | 4.3 | | 6.1 | 10.6 | | | | | 11.7 | 9.6 | | | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| - N-loss + NO3 = 5 | | | | | 4.3 | | 6.1 | 10.6 | | | | | 11.7 | 9.6 | | | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| - Erosion = 5 | | 90.0 | 2.6 | | | | | | | | 13.4 | | | | 6.1 | | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| - 30/20 | | | | | | 9.6 | 10.8 | 2.7 | | | | | 16.0 | | 3.2 | | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| - 15/10 | | | | | 16.0 | 9.6 | | 3.9 | | | | | | | | 12.8 | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| - 15/10/ 5 | | | | | 16.0 | 9.6 | | 3.9 | | | | | | | | 12.8 | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |
| Required no-tillage | 65.0 | | 16.0 | 9.6 | | | | | 67.0 | | | | | | 6.1 | | 7.9 | | 193.0 | 128.0 | 79.0 | 400.0 |
| Fall fertilizer ban | | | 16.0 | 9.6 | | | 1.2 | 5.3 | | | | | | | 12.8 | | | 7.9 | 193.0 | 128.0 | 79.0 | 400.0 |