A LONG TERM ANALYSIS OF THE IMPACT OF WHEAT TILLAGE SYSTEMS ON SOIL EROSION AND PRIVATE AND SOCIAL RETURNS IN NORTH CENTRAL OKLAHOMA

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CHAPTER I

INTRODUCTION

Problem Identification

Society should be concerned about soil erosion for two reasons. First, soil has unique physical, biological and chemical properties, which with other inputs and technology is the base for the production of the society's food and fiber needs. But continuous excessive erosion which causes thinning of soils, removes plant nutrients, and changes these desirable properties, jeopardizes the sustainability of high levels of food and fiber production indefinitely. Social policy is then recommended to reduce soil erosion so that the potential productivity of land for future generations is maintained.

The productivity impact of soil loss is not easily observable because of technological advances. Research has indicated that the potential productivity loss would be greater with technological growth than without it (Young et al., 1985). However, previous technological development has been soil-saving (Crosson and Brubaker, 1982). That means more food and fiber were produced on smaller acreage with the present technology than with the past technology. Nevertheless, when technical changes are coupled with increasing domestic and export demand, soil erosion increases because cultivation on marginal soils is more profitable than it would be otherwise.

The second reason for social concern about soil erosion is the existence of external costs. Soil erosion carries sediment and chemicals which affect the surface water quality and causes damage to canals, reservoirs, and lakes. These costs are external to private farm operators. Hence farm operators have no incentives to reduce these costs. Public policy is again recommended to correct the situation.

The type of tillage equipment used in the farming is an important factor affecting soil erosion. Landowners and farm operators make decisions about the type of alternative tillage systems based on their net returns. The decision should involve a long-term analysis of net returns to account for the long-term impact of soil erosion on productivity.

This study will consider three issues important to the economics of soil conservation. These are the long-term profitability of alternative tillage systems, the impact of technological advances and the impact of soil conservation policy. This dissertation will address these three issues using data from a county in North Central Oklahoma.

Study Area

The study area is Grant County, Oklahoma. Grant County is one of the top two wheat producing counties in Oklahoma. The county was selected in an earlier study (Aw-Hassan and Stoecker, 1992), because recently completed soil survey and a geographical information were available. The location of the county is shown in Figure 1.1.

Objectives and Methodology

The primary objective of this research was to assess whether it would be in the long-term interest of private producers and the society to adopt conservation tillage systems for wheat production in Grant County Oklahoma.

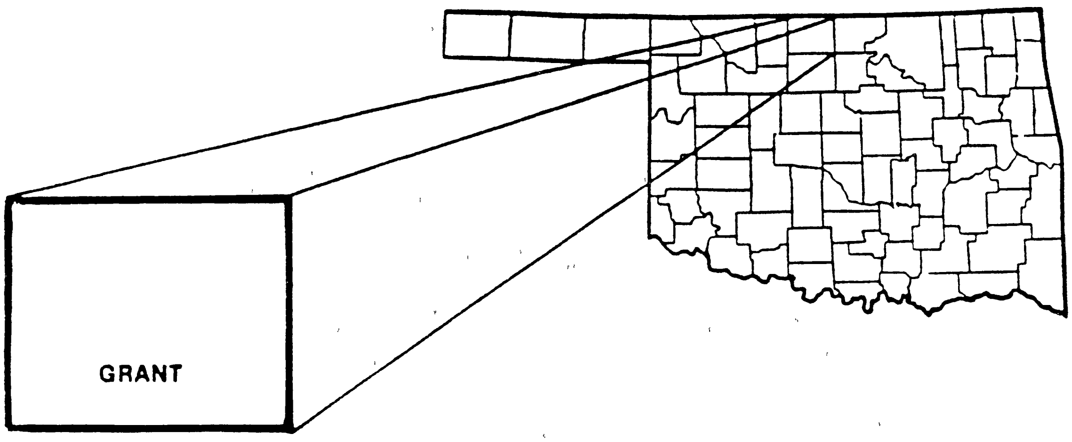


Figure 1.1. Grant County, Oklahoma.

Source: SCS, 1985.

Specific objectives were:

1) To compare the net present value of returns for alternative tillage systems for wheat by soil map unit (soil type).

2) To determine the impact of erosion limits and erosion tax on the choice of tillage systems for wheat and farm income under various assumptions regarding the discount rate, technological improvement, and wheat prices.

The methodologies used to meet these objectives will include a simulation model that projects yields for very long period of time given weather and soil data. Crop budgets and projected yields were used to estimate net present value of alternative tillage systems for different soils in the county. A dynamic economic model was developed for representative farms to evaluate the impact of technology, discount rates, prices and different conservation policy instruments on the choice of alternative tillage systems for wheat.

The Dissertation Content

The remainder of this dissertation is outlined as follows. In chapter 2, the soil erosion process, its impact on productivity and on the environment and policy issues are discussed. Both on-site productivity as well as the external damages from soil erosion are considered. In chapter 3, a basic non-renewable exhaustible resource model is outlined. The fundamental concepts of dynamic programming and optimal control theory which are used to solve intertemporal allocation problems are also briefly introduced. In chapter 4, a dynamic economic model of soil erosion is developed. The necessary conditions for optimal soil resource use are derived in discrete-time and continuous-time frameworks. An empirical discrete-decision model is also presented. In chapter 5, the data requirements, simulation and estimation procedures are detailed. In chapter 6, the assumptions for the analysis and the results of the empirical models are presented and discussed. Finally, in chapter 7, a summary and the conclusions drawn from the results are presented.

CHAPTER II

SOIL EROSION, IMPACT, AND POLICY

Soil Erosion: Process and Prediction

Soil erosion is the process of detachment and transportation of soil particles by erosive agents. The erosive agents are raindrops and surface runoff for sheet and rill erosion and wind for erosion by wind. In the case of wind erosion the process is described as creep, saltation, abrasion and suspension (SCS,1988). Soil erosion is a continuously occurring natural process. However, human activities, like cutting and clearing natural vegetative cover from land for crop and livestock production or for construction sites, accelerate the rate at which soil erodes beyond its geological levels (Pierce, 1990). When these accelerated soil erosion rates continue unabated for a long period of time the soil's production potential for food and fiber can be impaired. Environmental resources, such as water bodies, water conveyance facilities, and water reservoirs can also be damaged by the deposition of sediments and chemicals dissolved in the runoff water.

The first question to answer to address the soil erosion problem is how much soil erodes from a parcel of land with known characteristics in a given period of time. The soil erosion research undertaken between 1930 and 1960 led to the development of the Universal Soil Loss Equation or the USLE (Wischmeier and Smith, 1978). The USLE is an empirically based model which predicts sheet and rill erosion by water. The equation is given as:

$$A = RKLSCP$$

where A is the average annual soil loss in tons per acre per year (TAY),

R is called a weather factor and it is an index combining the rainfall amount and intensity,

K is the soil erodibility factor which accounts for the soil characteristics including texture, organic matter content and permeability, which affect soil's erodibility.

L is the slope length factor.

S is the slope steepness factor.

C is the management factor which accounts for the canopy and crop residue which protect the soil from the striking force of raindrops and slows down run off water.

P is the support practice factor and it reflects the use of contour farming, contour-strip cropping and terraces. The parameters and their derivation are discussed more completely in Wischmeier and Smith (1978).

An equation for the prediction of erosion by wind, known as the Wind Erosion Equation or WEQ was developed by Woodruff and Siddowey (1965). The relationship is

$$E = f(I, K, C, L, V)$$

where E is the estimated average annual soil loss in TAY.

I is the soil erodibility index.

K is the ridge roughness factor.

C is the climate factor.

L is the unsheltered length of eroding field factor

and V is the vegetative cover factor.

The relationships among the parameters are not simple products, but defined by a set of tables, graphs and monographs (SCS, 1988).

The USLE and WEQ have been widely used by the SCS technical staff to help farmers to design conservation plans. The equations have also been used in the nationwide surveys which are part of the National Resource Inventory (NRI) for 1977 and 1982. The extent of the soil erosion problem is sometimes expressed in terms of total gross erosion per year. Table 2.1 indicates the total gross erosion from sheet and rill in 1982 and other erosion in 1977 (Strohbehn, 1986).

Gross erosion is an estimate of the volume of the soil movement but this is not necessarily the amount leaving a particular field or farm. More than 5 billion tons of soil were moved by water in 1982. About 35 percent of this was from cropland (Table 2.1). Total gross erosion is not a complete indicator of the extent of erosion damage. Gross erosion does not distinguish between rates for different soils and it does not tell whether these rates are tolerable from productivity or an environmental standpoint. Soil tolerance loss (T-value) is defined as "The maximum rate of annual soil erosion that may occur and still permit a high level of crop productivity to be maintained economically and indefinitely" (Wischmeier and Smith, 1978). T-values, based on rates of soil formation, are usually estimated to be within the range of 2 to 5 TAY. However, the concept of the T-value has been criticized because of the lack of scientific basis and economic criteria, (Schertz, 1983 and Crosson,1986).

The USLE is an empirically based model and a number of deficiencies have been pointed out in the literature. First the USLE does not fully represent all the relationships among the variables that constitute the complex process of

TABLE 2.1

GROSS SHEET, RILL, AND OTHER EROSION BY SOURCE AND FARM PRODUCTION REGION, 1982

Region	Sheet and rill erosion				Other erosion (1977)1/			Total2/
	Cropland	Pasture	Range	Forest	Gullies, roads, and construction	Stream-bank	Quarries, pits, and mines	
				Million Tons				
Northeast	65.5	6.2	0.0	18.5	24.7	23.4	46.5	184.8
Lake States	129.9	5.8	0.1	11.4	16.2	10.8	7.0	181.3
Corn Belt	689.0	58.7	0.7	54.9	36.1	75.2	54.9	969.7
Northern Plains	281.8	7.9	82.6	4.0	79.9	97.3	117.9	671.4
Appalachian	181.9	47.6	0.0	68.0	58.5	36.6	91.6	484.2
Southeast	94.0	5.0	0.4	22.1	57.7	19.9	50.6	249.8
Delta States	116.3	11.5	0.3	21.0	28.5	41.9	14.4	233.9
Southern Plains	112.4	20.4	144.6	16.4	86.9	91.2	18.3	490.2
Mountain	89.5	2.5	446.3	233.4	103.6	83.1	44.3	1,002.7
Pacific	66.6	3.3	185.9	277.5	51.2	73.4	11.2	669.1
Total2/	1,827.9	168.9	861.1	727.2	543.4	552.9	456.8	5,137.3

Source: Strohbehn (1986), p. 16.

1/ Estimated from 1977 Conservation Needs Inventory. 1982 estimates not available. Does not include wind erosion.

2/ Detail does not add to totals due to rounding.

soil erosion nor does the current form of the equation include all the relevant variables (Elliot et al., 1990). Secondly, USLE predicts gross erosion rather than net soil loss or the amount of total eroded soil which ends up in the water ways (Crosson and Stout, 1983). The main deficiencies in point erosion models like the USLE and WEQ are that the models do not predict the amount of eroded soil which leaves the watershed.

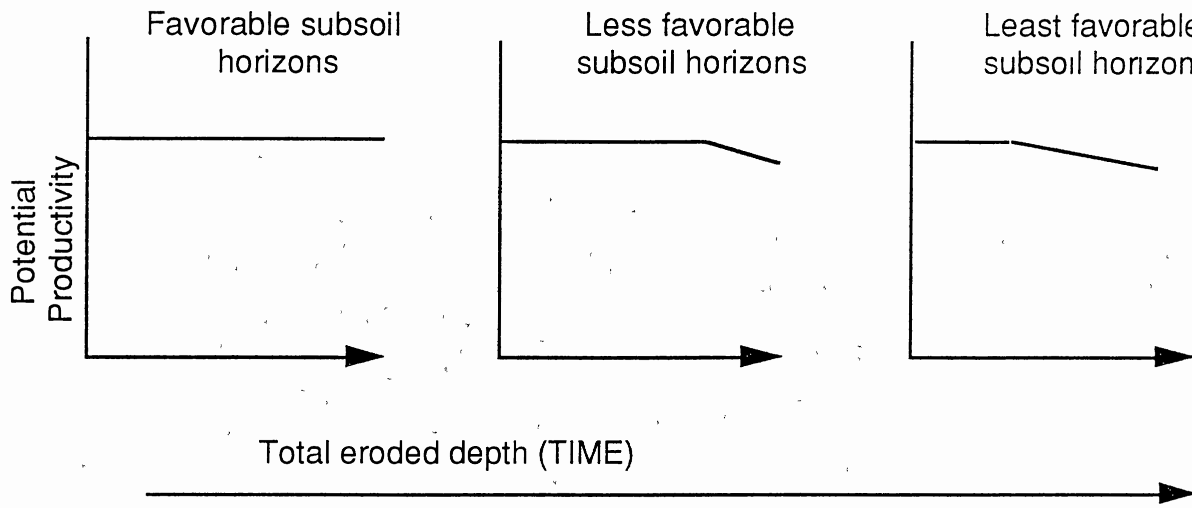
The sediment-delivery ratio is a measure of the amount of eroded soil that reaches the waterways relative to the total erosion. This ratio depends on many factors including soil characteristics, the number of channels in the water shed, the location of the eroded site relative to the stream and watershed size (Clark et al., 1985). In order to overcome the deficiencies in the USLE and the WEQ a research effort has been focusing on the "process-based" models of soil erosion prediction. The process-based models are generally computer simulation models which combine the fundamental erosion processes and fundamental hydrological processes via complex mathematical relationships. These models are expected to replace the USLE and WEQ. The WEPP or Water Erosion Prediction Project which is a cooperative work of the ARS, SCS, Forest Service, Bureau of Land Management, U.S. Geological Survey, and other cooperators is expected to generate a process-based erosion prediction model that will replace the USLE (Foster, 1987). Similarly, a process-based model called WEPS or wind erosion prediction system is underway to replace WEQ (Hagen, 1988). More accurate predictions of soil erosion will permit users to make reasonably accurate estimates of the on-farm and off-farm effects of the soil loss.

Erosion's Impact on Productivity

Soil erosion alters the soil physical and chemical characteristics by the removal of the surface layers and/or by the deposition of sediments. Whether soil erosion has a negative, positive or no effect on productivity depends on the the soil type, depth, and the time period over which erosion occurs. The formation of river deltas around the world and their contribution to world crop productivity is commonly cited as an example where soil erosion has a positive impact on productivity. Another case cited by Crosson and Stout (1983) is a farmer in western Iowa, who uses erosion as a land leveling technique.

Although in some situations erosion can increase productivity, the major concern of researchers and public policy makers, however, is the negative impact of soil erosion on crop productivity. Soil erosion negatively affects crop yields by removing the essential plant nutrients and by changing the physical soil properties such as resistance to root growth, permeability, and water-retention capacity. Erosion's effect, nonetheless, depends on many factors. One of these factors is the nature of the subsoil layers. Figure 2.1 depicts the decline of crop productivity for three soils that have subsoil horizons of varying characteristics. The soils that have the least favorable subsoil horizons have the greatest potential productivity losses from soil erosion. Conversely, there may be no productivity loss from a soil with deep and fertile subsoil horizons. Other factors affecting the impact of erosion on soil productivity include landscape position, crop management, technology and weather conditions.

There are two types of studies which assess the effect of soil loss on productivity. The first type are microstudies which deal with experimental data



Source: redrawn from Pierce et al. (1983).

Figure 2.1. Rates of productivity decline in different subsoil horizons.

or with data limited to specific sites. The second type are macrostudies which involve large geographical areas and often deal with regional or national data.

Microstudies

Most of the experimental research on the impact of erosion on productivity was conducted between 1930 and 1950. That research effort has produced a body of knowledge which has established the negative relationship between topsoil depth and crop yields. Pierce (1990) listed 55 studies conducted at experiment stations scattered around the United States from 1935 to 1980. The crops reported in the studies include corn, wheat, sorghum, cotton, millet and clover. Forty-nine out of the 55 studies reported that crop growth or yields declined when the top soil depth was reduced. In only one case was it reported that soil from cut area was more productive than soil from unaltered site. The remaining 5 studies have shown no difference in crop growth or yield.

Lyles (1975) summarized the results of eleven microstudies of the impact of soil loss on productivity shown in Tables 2.2, 2.3 and 2.4. As indicated the percent of yield reduction per inch of soil loss is very similar among the crops and regions of the United States.

TABLE 2.2

EFFECT OF TOPSOIL THICKNESS ON WHEAT YIELDS

Location	Yield Reduction per Inch of Topsoil (bu/a)	Yield Reduction per Inch of Topsoil (%)	Remarks
Wooster, Ohio	1.7	9.5	virgin soil
Columbus, Ohio	1.3	5.3	cropped soil
Oregon	1.0	2.2	deep soil
Oregon	2.5	5.8	thin soil
Oregon	2.0	6.4	thin soil
Wooster, Ohio	1.5	6.2	
Geary County, Kansas	1.3	6.2	
Palouse Area, Washington	1.6	6.9	loss of top 5 inches
Palouse Area, Washington	1.8	5.3	loss of top 11 inches
Pullman, Washington	1.4	2.9	
Manhattan, Kansas	1.1	4.3	Smolan silty clay loam
Akron, Colorado	0.5	2.0	Weld silt loam
Average	1.5	5.3	

Source: Studies cited in Lyles (1975).

TABLE 2.3

EFFECT OF TOPSOIL THICKNESS ON CORN YIELDS

Location	Yield Reduction per Inch of Topsoil (bu/a)	Yield Reduction per Inch of Topsoil (%)	Remarks
Geary County, Kansas	3.5	7.5	
Bethany, Missouri	3.0	6.4	Shelby and Grundy silt loams
Bethany, Missouri	4.0	6.0	Shelby and Grundy silt loams
Fowler, Indiana	4.0	4.3	Fowler, Brookston, and Parr
Fowler, Indiana	3.8	5.5	silt loams
Shenandoah, Iowa	6.1	5.1	Marshall silt loam
Greenfield, Iowa	3.2	5.0	Tama silt loam
Greenfield, Iowa	3.1	6.3	Shelby silt loam
Coshocton, Ohio	5.2	8.7	
Clarinda, Iowa	4.0	5.1	Marshall silt loam
Upham, North Dakota	3.4	7.4	
Wooster, Ohio	4.8	8.0	Canfield silt loam
Columbus, Ohio	3.0	6.0	Celina silt loam
East Central, Illinois	3.7	6.5	Swygert silt loam
Average	3.9	6.3	

Source: Studies cited in Lyles (1975).

TABLE 2.4

EFFECT OF TOPSOIL THICKNESS ON GRAIN SORGHUM YIELDS

Location	Yield Reduction per Inch of Topsoil (bu/a)	Yield Reduction per Inch of Topsoil (%)	Remarks
Bushland, Texas (irrigated)	3.0	5.2	Pullman silty clay loam
Bushland, Texas (pre-irrigation only)	2.0	4.1	Pullman silty clay loam
Temple, Texas (non-irrigated)	2.1	5.7	Austin clay
Average	2.4	5.0	Austin clay

Source: Studies cited in Lyles (1975).

Three major symposiums have been conducted in the United States where the results of past research and recent findings have been published (ASAE 1985), El-Swaify (1985), and Follett et al. (1985). Battiston et al. (1985) reported that corn grain yields declined by an average of 30 percent on moderately to severely eroded soils from field trails conducted over a two-year period. The decline was attributed to nutrient deficiencies and plant-water availability. Carter (1985) concluded that crop productivity has been reduced about 10 percent by erosion that has occurred over the past 75 to 80 years.

In general three methods were used in these microstudies to determine the impacts of soil erosion on productivity. The methods were 1) comparing yields between plots with different erosion phases 2) comparing yields from sites where topsoil was artificially truncated (cut and fill) with yields from sites with unaltered topsoil and 3) Using a multiple regression analysis to model crop yields as a function of soil characteristics.

In spite of the past research efforts and convincing results indicating that soil loss reduces crop yields, the complexity of the factors determining crop-productivity has raised more questions. It is now recognized that the soil loss productivity relationship is more complex than was indicated in the past. Lal (1987) states that "we cannot say for sure what effect the loss of a unit of soil depth has on crop yield." The distinction has been made between renewable and non-renewable soil resources. For example the loss of inherent soil fertility may have a little impact on long-term potential productivity since plant nutrient requirement can be effectively managed (Battiston, 1985). However the loss or reduction of plant-available water-holding capacity and changes in structural properties are more difficult to restore and, therefore, will have a greater long-term impact on productivity (Williams, 1981).

<u>Macrostudies</u>

There are five macro level studies on the long-term impact of erosion on productivity which are reviewed below. The studies were done by Hagen and Dyke (1980), Putman and Associates (1988), Crosson and Stout (1983), Pierce and Associates (1984) and Colacicco and Associates (1989). The methodology used and conclusions of each study will be briefly stated.

Hagen and Dyke (1980) developed a yield/soil loss simulator, in which yield was a function of soil characteristics. The authors merged data from six different sources and applied the model to the 1985 RCA appraisal. They concluded that over the next 100 years soil loss would reduce productivity in the United States by 8 percent. Their analysis was the first attempt to use a consistent national data base and model to assess the impact of soil erosion on productivity.

Putman and Associates (1988) used the Erosion Productivity Impact Calculator (EPIC) for the 1985 RCA appraisal. The authors used the EPIC model to simulate soil productivity with no erosion (or with full erosion control) and without erosion control. Ratios of the annual yields for the two estimates were pooled together for all tillage and crop sequence alternatives to estimate an "erosion productivity coefficient". The coefficient gave the percent loss in productivity per ton of erosion. However, the statistical significance of those coefficients were not reported. The coefficients were used to estimate the long-term impact of erosion on productivity. It was assumed that erosion rates and the mix of management, tillage, and conservation practices would remain the same as they were recorded in the 1982 NRI Survey. Table 2.5 gives the productivity loss by type of erosion and by region. The productivity loss ranged from 0.9 percent in the Northern Plains to over 7.1 percent in the Northeastern region of the U.S. The authors concluded that national productivity would be reduced by 2.3 percent in 100 years.

Pierce and Associates (1984) used a modified version of a model developed initially by Kiniry and Associates (1983) to estimate the long-term productivity declines caused by soil erosion in the corn belt of the United States. The model defines a productivity index (PI) which is related to the adequacy of the soil as a rooting environment. Specifically the model accounts for

TABLE 2.5

POTENTIAL PRODUCTIVITY LOSSES FROM EROSION*.

	Productivity Loss in the 10th Year					
	Sheet and Rill Erosion			Wind Erosion		
Region	Percent	Equivalent Acre	Gross Product	Percent	Equivalent Acre	Gross Product
Northeast	7.1	1,108	330	#	3	1
Lake States	0.9	424	124	0.7	255	47
Corn Belt	3.5	3,483	961	#	6	2
Northern plains	0.6	417	95	0.3	192	35
Appalachia	4.7	883	232	#	#	#
Southeast	1.3	195	52	#	#	#
Delta	1.6	304	72	#	#	#
Southern Plains	0.2	71	16	2.1	573	161
Mountain	0.4	443	15	1.4	442	74
Pacific	2.3	518	74	0.2	77	15
Total	1.8	7,428	1,972	0.5	1,548	335

Source: Putman and Associates (1988).

* Productivity loss is computed from EPIC simulations. Equivalent acre loss is computed as the summation of percent loss of productivity in 100 years times total acres.

\# Less than .05 percent, .05 million acres, and .05 million dollars.

"sufficiency" of the soil's characteristics such as bulk density, available water capacity, permeability and PH (a measure of acidity) for each soil layer. Those sufficiency values are determined and weighted for each layer by the rooting biomass distribution. Since lower layers have a smaller proportion of the root biomass distribution they will have less weight in the contribution to the PI. The study covered an area of 72.9 million acres in the Corn belt. Table 2.6 shows the Major Land Resource Areas (MLRA) and the percent decline of the PI by slope range. The general conclusion of the study was that, under current management, the erosion rates from the 1977 NRI erosion meant the PI decline for the corn belt region over the next 100 years would be less than 8 percent. But as the table indicates, the productivity index decline is more severe in some soils than in others. Shallow soils or soils with unfavorable underlying material will, generally, show the greater yield declines from erosion. Deep, fertile soils or soils with favorable subsoils can tolerate erosion with little productivity loss.

Crosson and Stout (1983) used a regression model in which the dependent variable was the trend value for yield and the independent variables were the rates of sheet and rill erosion from the 1977 NRI, potential erosion or RKLS (this is USLE without C and P factors), the average yield in a county and county dummy variables. The county data used was from 1950 to 1980 for the corn, wheat and soybeans crops in the regions of cornbelt, Northern Plains and the Palouse region of the Pacific northwest. The analysis assumed that the intercounty yield trend differences were explained by the intercounty differences in the erosion rates. Intercounty differences in input use, technology and soil quality were not explicitly included in the regression.

Table 2.7 shows the percentage decline in crop yields trend due to sheet and rill erosion by rate of erosion for corn, soybeans and wheat. The authors concluded that overall, erosion reduced trend values of soybeans and corn yields in 1980 by 1.5 to 2.0 percent. That means, for example, corn yields in 1980 were 2 percent lower due to erosion than was expected given the 1950 to 1980 trends of yield growth. The reduction of yield trend values for wheat were negligible according to this study.

TABLE 2.6

CHANGE IN THE PRODUCTIVITY INDEX BY SLOPE CLASS
AS FOR EACH MLRA IN THE CORNBELT

	Percent Change in PI				
	Slope Range (%)				
MLRA	0-2	2-6	6-12	12-20	20-45
102A	1	2	5	6	n.a.
102B	1	2	5	3	7
103	1	4	15	19	10
104	1	3	8	4	0
105	1	3	5	20	40
106	1	7	9	5	n.a.
107	1	2	5	4	2
108	1	2	6	8	5
109	2	5	13	9	39
110	2	9	48	n.a.	48
111	3	8	22	36	61
112	4	11	17	100	n.a.
113	2	6	13	38	7
114	2	7	21	4	n.a.
115	1	4	10	6	2

Source: Pierce and Associates (1984). Summarized from Table 5-9.
n.a. = not available.

TABLE 2.7

ESTIMATED EFFECTS OF EROSION ON THE TREND
OF CROP YIELDS, 1950-1980

	Reduction in Yield Trend Because of Erosion as a Percentage of Mean Yield Trend			
		Erosion on Rate Class (USLE) Ton's per acre		
Crop	All	< 5	10-20	> 20
Corn (616 counties)	4	n.a.	n.a.	n.a.
Corn (341 counties)	1	3	18	3
Soybeans (299 counties)	4	4	22	2
Wheat (191 counties)	1	d	n.a.	n.a.

Source: Crosson and Stout (1983), from Table 5-9.
d = less than 1 percent
n.a. = not available

Colacicco and Associates (1989) used EPIC to determine the effects of soil erosion on crop yields and fertilizer use. The researchers then combined these effects with erosion rates from the 1982 NRI to estimate the yield losses from soil erosion over the next 100 years. Colacicco and Associates, assuming a constant technology, concluded that average future yields for corn, soybeans, and cotton will decline by 4.6, 3.5, and 4.5 percent, respectively. Average yields of wheat were estimated to decline by 1.6 percent.

Off-Site Damage

Besides the impact on productivity, soil erosion has a great impact on environmental resources outside the farm. Sediments carried by runoff water into the streams and water bodies fill reservoirs, navigation canals, water conveyance facilities, and affect aquatic organisms. Nutrients from chemical fertilizers and animal manure, are attached to the sediment and dissolve in the run off water. These nutrients increase the growth of aquatic vegetation, decrease fish population and deteriorate water quality. Consequently, the values of recreational activities (such as fishing, boating and swimming) are decreased and the maintenance cost of dredging of lakes and canals is increased. Pesticides carried with runoff water and sediment affect aquatic organisms both directly and indirectly through the food chain and increase the health risk to humans. Clark et al. (1985) conducted the first comprehensive evaluation of off-site damages caused by soil erosion. The estimates are given in Table 2.8. Clark et al. estimated that soil eroding from all sources caused $6.1 billion annually (1980 dollars) in damage to instream facilities and off-stream water uses. They attributed about $2.2 billion of this damage to cropland erosion. Young and Osborn (1990) in an evaluation study of the CRP

TABLE 2.8

ESTIMATED ANNUAL OFF-SITE DAMAGE COSTS
(MILLION 1980 DOLLARS)

Type of impact	Range of estimates	Single-value estimate	Cropland's share
In-stream effects			
Biological impacts		no estimate	
Recreational	950-5,600	2,000	830
Water-storage facilities	310-1,600	690	220
Navigation	420- 800	560	180
Other in-stream uses	460-2,500	900	320
Subtotal--In-stream (rounded)	2,100-10,000	4,200	1,600
Off-stream effects			
Flood damages	440-1,300	770	250
Water-conveyances facilities	140- 300	200	100
Water-treatment facilities	50- 500	100	30
Other off-stream uses	400- 920	800	280
Subtotal--Off-stream (rounded)	1,100-3,100	1,900	660
Total--all effects (rounded)	3,200-13,000	6,100	2,200

Source: Clark et al. (1985). p. 175

estimated the present value of off-farm benefits of the program, when all 45 million acres were taken out of production, to range $6.0 to $13.6 billion (1986-99), while the on farm productivity benefits were only $0.8 to $2.4 billion. This illustrates that off-site benefits of erosion control are significantly greater than the productivity benefits.

Conservation Tillage, Adoption and Policy

Soil conservation research has continued since the 1930's and produced many technologies that are used by farmers. Soil conservation technologies include conservation tillage, terraces, contour farming and strip cropping. The United States Department of Agriculture considered conservation tillage as the most cost effective method for soil and water conservation (USDA, 1980). Conservation tillage is defined as any tillage system which leaves at least 30 percent of the crop residue on the soil surface after planting (Allmaras et al., 1990). Conservation tillage sometimes includes any tillage system that reduces the number of field operations compared to the conventional tillage even if the 30 percent surface residue requirement is not strictly satisfied. For example, disk and chisel based tillage systems are considered conservation tillage (Allmaras et al., 1990).

Conservation tillage has two major objectives: to control soil erosion and to conserve soil moisture. Crop cover and the residue on the soil surface intercept the energy of rain drops, reduce the rate of the surface water run off and decrease the surface wind velocity. Consequently, soil erosion is reduced. Also, by increasing the rate of water infiltration potential water storage is increased (Unger et al., 1977).

The adoption of conservation practices in the short-term depends on the net returns and the associated risk. The short-term profit of conservation tillage depends on its impact on crop yields (in the short-term) and on weed and pest control. Research indicates that crop yields may be greater under conservation tillage where soil moisture is a limiting factor. But effective weed control is required to get the full benefit of moisture conservation (Fenster, 1977, Unger et al., 1977). Yields under conservation tillage may also be comparable with those under conventional tillage in well drained soils. However, yields will be lower under conservation tillage on poorly drained soils. Surface cover holds moisture under the soil surface for a longer period of time which then reduces soil temperature. Low soil temperature causes poor germination and delays planting (Griffith et al., 1977). Consequently yields will be lower. Soil temperature also affects the denitrification process. Fenster (1977) states that as a result of low temperatures, increased nitrogen application is often needed to compensate for the nitrate tied up in the residue. Yields under conservation tillage may also decline due to ineffective weed control. Herbicide application could effectively control a wide variety of weeds under conservation tillage. However, if the additional cost of herbicides is not offset by the reduced cost of fuel, machinery, and labor, conservation tillage will have lower net returns. Other problems of conservation tillage include volunteer plants which raise the potential for spread of diseases in the new crop (Fenster, 1977).

Adoption of conservation tillage also depends upon the farmer's attitude towards risk. Allmaras et al. (1990) pointed out that even with the significant improvements made in weed control as well as in tillage and planting machinery systems since 1980, there remain a wide range of technological deficiencies which increase the risk of failure and, thus, hinder adoption of conservation tillage. Other obstacles to the adoption of conservation tillage include weed control, financial constraints, grower attitude, inadequate equipment, poor net profit, difficult crop residue management, disease and insect control, fertilizer management, and lack of adapted plant varieties.

Fletcher and Sietz (1986) reported the majority of farmers surveyed indicated that they would invest in conservation tillage equipment if they were convinced that conservation tillage was at least as profitable as conventional tillage or that at least it did not lower their profits. A few farmers indicated they would accept a penalty (up to $10 per acre) and still use conservation tillage. The later group of farmers who were willing to accept the penalty might have foreseen the future productivity gains.

Let us assume that the bottom line of the farmer's decision is economics. If conservation tillage is treated as a new technology that would ensure greater efficient use of inputs (including time) and, increase profits, then farmers would adopt it and the adoption process will not be different from any other new agricultural innovation. The only public policy required in that situation would be research and education support programs. However, if the conservation tillage has lower short-term profits, farmer's decision based on a short-term profit maximization will not ensure the adoption of conservation tillage. In these situations soil erosion would be above the levels that were socially optimal and a more direct public policy would be called for to correct the situation. Research and education alone will not be enough to reduce soil erosion.

Swanson et al. (1986) pointed out that short-term profit is the major factor determining farmer's decisions. Swanson et al. argued that farmers are pressured by the competitive nature of the agricultural industry and due to financial constraints, debt burden, and other factors, farmers will adopt practices that maximize short-term profits to survive. Obviously short-term profit maximization does not fully account for the value of the farmer's most important asset, land. Land is a capital asset and the landowner can be assumed to seek to maximize the present value of the stream of net returns over a planning horizon plus a final resale value at the end of the planning horizon. Thus, like any other capital asset, the landowner would protect the market value of his capital. If discounted expected returns are greater than the discounted costs then the conservation investment will be carried out. Otherwise no conservation investment will occur. Assuming no off-site damage costs, this decision rule suggests that farmers will protect against any productivity loss due to erosion if it is economical, so the society can rely on the farmers. The rule, nevertheless, has to pass a test before it is accepted. First land owner's discount rate must be the same as the society's discount rate. Secondly, the land market must reflect the soil productivity and thirdly, the landowner must have information about the impact of soil erosion on long-term soil productivity.

The social discount rate can be lower than the private discount rate for economic, institutional or ethical reasons. The economic reasons include that the private individual bears higher risk than the society and that private individuals who have pressing financial needs may discount future needs (Easter and Cotner, 1982). Age and income level also effect discount rate. Among the institutional arrangements that may affect private discount rate are the type of lease arrangements. Ervin (1986) points out that insecurity of tenure or problems in the distribution of conservation benefits and costs between landlord and tenant result in short planning horizon and higher discount rate. The ethical issue of intergenerational equity may require the social discount to be very low or even zero.

Based on results from study in Iowa, Miranowski (1986) states that both top soil depth and erodibility were significant in explaining county and farm-level differences in land values, which was taken as an indication that the "Land Market Works". One reason why land prices may not properly reflect returns from soil conservation investment is that buyers cannot easily determine how much soil has eroded, unless the erosion is severe (Ervin and Mill, 1985; Gardner and Barrows, 1985). However, even if the land market works, it may not work perfectly. Easter and Cotner (1982) point out that distorted capital markets will have an effect on long-term investment. Also uncertainty about future world food demands, production technologies, and resource productivity may or may not be included in market value of land.

The question of farmers' information was also tested by Miranda (1992), who concluded that farmers when bidding for Conservation Reserve Program land retirement payments did not consider the productivity gains from soil conservation. That was explained by lack of adequate information about the impact of soil erosion on productivity.

The case for a public policy in soil conservation to maintain long-term productivity, assuming zero off-farm costs, can be summed up by the ethical issue of intergenerational equity. Brubaker and Castle (1982) explicitly stated it as ". . . A socially optimal level of conservation may not be a purely economic one. Acceptance of the ethical standard giving equal weight to the future is what justifies public intervention in soil conservation matters". Crosson (1986) discussed this issue in great length. Crosson first accepts the notion that it is the responsibility of every generation to ensure that its actions should not increase the production cost of food and fiber for future generations. Then using estimates of the decline in long-term productivity as a result of erosion, Crosson projected that the annualized cost of the erosion-induced loss of crop output was only 1 percent of the total projected cost of production. Therefore, Crosson concluded that even if the goal was to reduce future production costs, reducing soil erosion alone would not make a significant impact. Crosson suggests that continuous technological development will ensure declining food production costs.

Off-farm damage caused by soil erosion is different from the erosion-induced productivity loss in that it is external to landowners. Landowners do not bear the off-farm costs, therefore they have no incentive in reducing these costs. Soil erosion rates that maximize landowners' profits, therefore, will not be socially optimal. Ideally the level of erosion control is determined by the marginal condition. The offsite damage costs from soil erosion are estimated, and the value of marginal damage cost per unit of eroded soil that reaches the affected site (or marginal benefit per unit of erosion reduced) is compared with the marginal treatment cost of erosion. The socially optimal erosion control is the level which equalizes the marginal social treatment cost and the marginal social benefit. The socially optimal erosion control is denoted by SOEC in Figure 2.2. Figure 2.2 shows that the marginal private benefits of erosion control (MPB) are less than the marginal social benefits (MSB) because the private individuals have a higher discount rate than the society and do not consider the external damages from soil erosion. Consequently, the privately optimal erosion control (POEC) is lower than the socially optimal erosion control (SOEC).

The approach described above requires knowledge of the damage functions from soil loss and treatment cost of all farms where eroded soil could potentially cause a damage to the environmental resources down stream. The estimation of the off-site benefits of soil erosion control can be taken up in three steps (Crosson and Brubaker, 1982). The first step is to develop a model which describes the transport and distribution of eroded soil from the point where erosion occurs to the different points where the damage occurs. The second step is to develop an environmental quality - soil erosion response function which gives, for example, the change in water quality as a result of one ton change in the sediment or the chemicals dissolved in the run-off water entering a lake. The third step is to estimate the society's willingness to pay for a marginal increment of the water quality. In general, as pointed out by Fisher (1981), the information required to estimate off-site damage functions is not easily available.

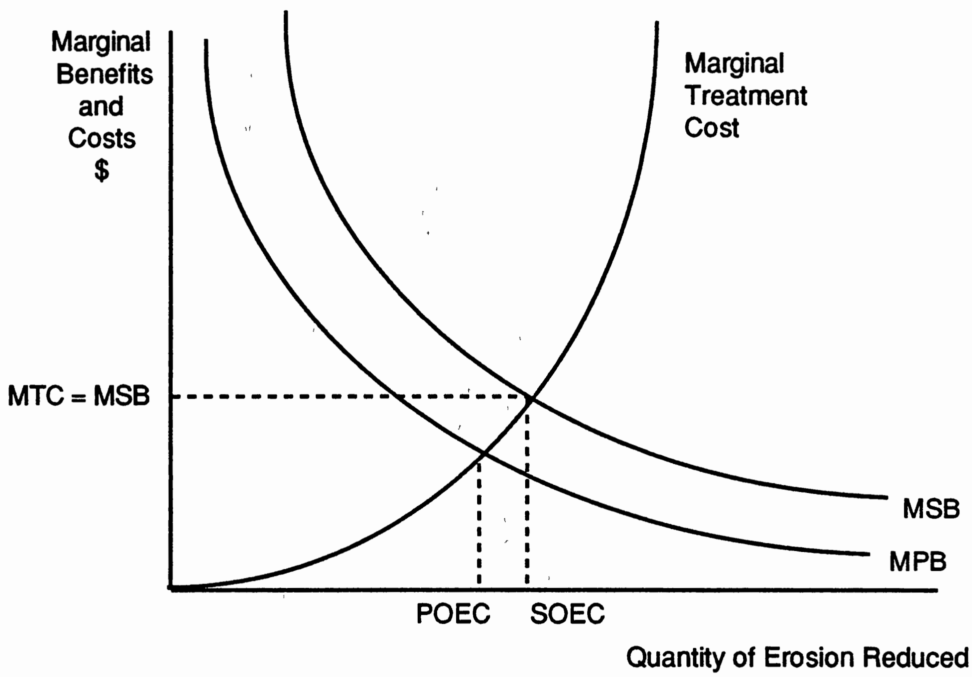


Figure 2.2. Socially Optimal Erosion Rate

Alternatively, the society can determine some level of socially acceptable standards of environmental quality and then determine policies that will reduce soil erosion rates to those standards at the minimum social cost. In general, there are four major alternative policies for soil conservation that will maximize net social benefits:

1) Support for research and education programs to develop more profitable soil-conservation technologies.
2) Provision of financial assistance, such as cost-sharing, loans and others, along with technical assistance to reach policy goals.
3) Requiring farmers cultivating highly erodible land to meet certain erosion standards to participate in the commodity programs.

4) Charging taxes or fines on the users of land (or soil) resource for tillage and farming systems that do not maximize net social benefits.

The first policy was an integral part of the history of the United States Department of Agriculture's effort in soil conservation. This policy focuses on providing farmers profitable soil conservation technologies through research. This policy alone is not enough and other policies that make more direct impact on soil conservation are necessary. The weakness of the second policy option above is its difficulty in targeting the payments and assistance accurately to the areas when it will yield the highest net social benefits.

Benefit-Cost methods can be used to compare alternative policies. The benefit cost analysis widely used in program evaluation is based on the "compensation principle". The principle states that a policy is socially beneficial if the gainers from the policy would be able to compensate the losers fully and still be better off. Actual transfer need not to take place, for the compensation principle to be satisfied, but benefits should exceed costs. Another technique used to evaluate programs is cost effectiveness analysis which measures the tons of soil saved per dollar of program expenditures. This approach implicitly assumes that the eroded soil had the same value in all locations regardless of the potential damage on the farm and outside the farm.

The choice between alternative policies, nonetheless, is not based solely on economic considerations. Political and social considerations are important as well. For example, an erosion tax may not be politically popular, while financial and technical assistance provides employment and enhances farm income.

CHAPTER III

A BASIC MODEL OF OPTIMAL USE OF EXHAUSTIBLE NON RENEWABLE RESOURCE

Before we discuss the Basic Model, we will briefly introduce dynamic programming and optimal control techniques which are used to solve economic problems, including economic growth, resource use, and capital investment, that require optimization over time.

Dynamic Programming

The dynamic programming problems are solved by using the Bellman's optimality principle which states that:

> "An optimal policy has the property that, whatever the initial state and decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision" Bellman (1957).

Let a dynamic programming problem or multistage problem be written as:

$$\text{Max } J = \sum_{t=1}^{T-1} u(s_t, x_t) + F(s_T, T) \tag{3.1}$$

Subject to $$s_{t+1} = f(s_t, x_t) \tag{3.2}$$

$$s_{(1)} = \text{a initial state is given.}$$

where J is the objective function value, U (•) is the profit function at time t , $F(s_T, T)$ is the value of the terminal state at time T, X_t is a sequence of control variables $(x_1, x_2, \ldots x_{T-1})$, s_t is the state variable at time t , and f (•) is a state transformation function.

Using the principle of optimality the multistage optimization problem above can be written as:

$$J^*(s_t, t) = \text{Max}\left[u(s_t, x_t) + J^*(s_{t+1}, t+1)\right] \tag{3.3}$$

which states that the optimal value of the objective function starting at state s at time t is equal to the maximum of the sum of the current period's profits and the optimal value of the remaining stock at time t+1. By substituting s_{t+1} from (3.2) we can rewrite (3.3) as:

$$J^*(s_t, t_t) = \text{Max}\left[u(s_t, x_t) + J^*\left(f(s_t, x_t), t+1\right)\right] \tag{3.4}$$

and the boundary condition is:

$$J^*(s_T, T) = F(s_T, T) \tag{3.5}$$

which states that the optimal value of the objective function given state s_T at time T is the value of the terminal state evaluated at time T. The dynamic programming problem can be solved by working backwards from the terminal time T to T-1, T-3, . . . 1; using equation (3.4).

Optimal Control Theory

Optimal control, like dynamic programming, is employed in solving intertemporal allocation problems. Optimal control theory is generally formulated in a continuous time context. It is helpful, however, to start with a discrete-time model using the Lagrangian multiplier technique.

Consider the dynamic allocation problem

$$\text{Maximize } W = \sum_{t=1}^{T-1} u(s_t, x_t) + F(s_T, T) \qquad (3.6)$$

$$\text{Subject to} \qquad s_{t+1} - s_t = f(s_t, x_t) \qquad (3.7)$$

$$\text{and} \qquad s(1) = a \qquad (3.8)$$

where W is the objective function value and a is the initial endorsement. Equation (3.7) is a difference equation which describes the change of the state variable determined by the function f(•). All other variables are as described earlier. The Lagrangian function can be written as:

$$L = \sum_{t=1}^{T-1} u(s_t, x_t) + \sum_{t=1}^{T-1} \lambda_t \left(s_t - s_{t+1} + f(\bullet) \right) + F(s_T, T) \qquad (3.9)$$

where λ_t is the Lagrangian multiplier. We can take the first partial derivatives of the Lagrangian function with respect to x, s, and λ. The first order necessary conditions for maximum are:

$$\frac{\partial L}{\partial x_t} = \frac{\partial u(\bullet)}{\partial x_t} + \lambda_t \frac{\partial f(\bullet)}{\partial x_t} = 0 \qquad t=1, \ldots . T-1 \qquad (3.10)$$

$$\frac{\partial L}{\partial s_t} = \frac{\partial u(\bullet)}{\partial s_t} - \lambda_{t-1} + \lambda_t \left(1 + \frac{\partial f(\bullet)}{\partial s_t}\right) = 0 \qquad t=1, \ldots . T-1 \qquad (3.11)$$

$$\frac{\partial L}{\partial \lambda_t} = s_t - s_{t-1} + f(s_t, x_t) = 0 \qquad t=1, \ldots . T-1 \qquad (3.12)$$

and

$$\frac{\partial L}{\partial s_T} = -\lambda_T + \frac{\partial F(\bullet)}{\partial s_T} = 0 \qquad (3.13)$$

The first order necessary conditions can be rewritten in a form that will be easily comparable with the continuous time formulation. The conditions are:

$$\frac{\partial u(\bullet)}{\partial x_t} + \lambda_t \frac{\partial f(\bullet)}{\partial x_t} = 0 \tag{3.14}$$

$$\lambda_t - \lambda_{t-1} = -\left(\frac{\partial u(\bullet)}{\partial s_t} + \lambda_t \frac{\partial f(\bullet)}{\partial s_t}\right) \tag{3.15}$$

$$s_{t+1} - s_t = f(s_t , x_t) \tag{3.16}$$

$$\lambda_T = \frac{\partial F(\bullet)}{\partial s_T} \tag{3.17}$$

$$s(1) = a \tag{3.18}$$

Conditions (3.14) through (3.18) are known as the "maximum principle" in a discrete-time context. The discrete-time maximum principle is discussed in detail by Whittle (1982), Varaiya (1972), Almon (1967) and Zangwill (1969).

If we assume a continuous time interval i.e. $0 \leq t \leq T$, and the difference equation describing the change of the state variable is replaced by a differential equation, the above problem becomes an optimal control problem which can be expressed as:

$$\text{Maximize } W = \int_0^T u\big(s(t), x(t), t\big)\, dt + F\,(s(T), T)$$

$$\text{Subject to : } \frac{ds}{dt} \equiv \dot{s} = f\big(s(t), x(t)\big)$$

$$\text{and} \qquad s(o) = a$$

A Hamiltonian function is defined as:

$$H\big(s(t), x(t), t\big) = u\big(s(t), x(t), t\big) + \lambda(t)\, f\big(s(t), x(t)\big)$$

where $\lambda(t)$ is called the co-state variable, similar to the Lagrangian multiplier in the discrete-time model.

The continuous-time counterparts of the maximum principle conditions given in equations (3.14) through (3.18) can be derived by taking the partial derivatives of the Hamiltonian with respect to the state variable, the control variable, and the co-state variable and equating them to zero[1].

The conditions are as follows:

$$\frac{\partial H}{\partial x_t} = 0 \qquad (3.14)'$$

$$\frac{d\lambda}{dt} \equiv \dot{\lambda} = \frac{-\partial H}{\partial s_t} \qquad (3.15)'$$

$$\frac{ds}{dt} \equiv \dot{s} = f\big(s(t), x(t)\big) \qquad (3.16)'$$

$$\lambda(T) = \frac{\partial F}{\partial s_{(T)}} \qquad (3.17)'$$

$$s(o) = a \qquad (3.18)'$$

Now we can compare conditions (3.14)' through(3.18)' with conditions (3.14) through (3.18). Condition (3.14)' is the maximum condition, conditions (3.15)' and (3.16)' are the adjoint equations and (3.17)' is the transversability condition. While (3.18)' is the initial value of the state variable. The economic interpretation of these conditions will be discussed in the following simple model of non-renewable resource allocation and again in chapter 4 where a dynamic soil erosion model is developed.

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1 For detailed discussion of the maximum principle see Bryson and Ho (1975), Conrad and Clark (1987), Intrilligator (1971). For a rigorous exposition of the theorem of the Pontrayagin maximum principle see Diliberto (1967).

The maximum principle will be used to get the optimality conditions and the time paths of the rates of resource use for a model discussed in the following section and for a soil erosion model presented in chapter 4.

The Basic Model

A model of natural resource use must reflect conditions of demand for the resource, cost of extraction and the technology for extraction. To present a simple model of resource use and derive conditions for the optimal time path we will suppress the technology. Let us assume that a mine owner has a stock of a given natural resource, s_t, in time time t. The cost of extraction $c(q_t , s_t)$, is a function of the quantity extracted, q_t, in time t and the remaining stock. We may also assume that cost is positively related to the quantity extracted, (i.e. $\partial c/\partial q > 0$), and negatively related to the stock available (i.e. $\partial c/\partial s_t < 0$). The benefit from the resource is the price multiplied by the quantity in each time period. Assuming a constant price over time we can write $B_t = p \cdot q_t$. The problem of the mine owner is, therefore, to maximize the net present value of the stock of natural resources given the constraint that only the available stock could be extracted.

The problem is presented as follows:[2]

$$\text{Maximize NB} = \sum_{t=1}^{T} \frac{pq_t - c(q_t , s_t)}{(1+r)^t} \qquad (3.19)$$

Subject to:

$$s_{t+1} = s_t - q_t, \ t = 1, \ldots . . T\text{-}1 \qquad (3.20)$$

$$s(1) = a \qquad (3.21)$$

2 The model discussed herein is based on a similar exposition given by Fisher (1981).

$$s_T = \bar{s}_T \tag{3.22}$$

where r is the discount rate.

The above described problem with certain qualifications constitutes the Pontryagin maximum principle in discrete-time framework (Whittle, 1982). The problem can be solved by setting up a Lagrangian and differentiating it with respect to s_t, q_t and the multipliers and setting the derivatives equal to zero. The Lagrangian function is written as:

$$L = \sum_{t=1}^{T} \frac{pq_t - c(q_t , s_t)}{(1+r)^t} + \sum_{t=1}^{T-1} \alpha_t (s_t - s_{t+1} - q_t) + \alpha_T (\bar{s}_T - s_T) \tag{3.23}$$

where α and β are the Lagrangian multipliers. Differentiating the Lagrangian with respect to q_t, x_t, and α_t and equating the derivatives to zero yields the necessary conditions for a maximum:

$$\frac{\partial L}{\partial q_t} = \frac{p - \partial c/\partial q_t}{(1+r)^t} - \alpha_t = 0 \text{ , } t=1, \dots . T \tag{3.24}$$

$$\text{or} \quad p - \frac{\partial c}{\partial q_t} = \alpha_t(1+r)^t \tag{3.25}$$

and

$$\frac{\partial L}{\partial s_t} = \frac{- \partial c/\partial s_t}{(1+r)^t} + \alpha_t - \alpha_{t-1} = 0 \text{ , } t=1, \dots . T \tag{3.26}$$

The Lagrangian multiplier, α_t is defined as the change in the maximum value of the objective function as a result of a unit change in the value of the state variable, (i.e. stock of the resource) at time t+1. Alternatively the Lagrangian multiplier, α_t, can be interpreted as the amount by which the discounted objective function value would decline if one additional unit of resource were extracted in time t instead of leaving it in the ground to be extracted in time t+1.

The Lagrangian multiplier, α_t, is referred to as the user cost or "shadow price" of the resources because it represents the value of future production given up because one additional unit is used at the present time. Equation (3.7) states that extraction should occur until the price of the resource, p, should be equated to the marginal cost of extraction in the current period, plus the user cost which is the undiscounted Lagrangian multiplier (or $\lambda_t = \alpha_t(1+r)^t$).

Equation (3.8) gives the second necessary condition for optimal extraction and it describes the behavior of the user cost, α_t, over time. Let us define:

$$\alpha_t = \lambda_t (1+r)^{-t} \tag{3.27}$$

where λ_t is the undiscounted user cost. By substituting α_t in equation (3.26) and multiplying both sides by $(1+r)^t$ yields:

$$\frac{-\partial c}{\partial s_t} + \lambda_t - \lambda_{t-1}(1+r) = 0$$

$$\text{or} \qquad \lambda_t - \lambda_{t-1} = r\lambda_{t-1} + \frac{\partial c}{\partial s_t} \tag{3.28}$$

Equation (3.28) indicates that the behavior of the user cost over time depends on the discount rate and the effect of remaining stock on the extraction cost. If the remaining stock has no effect on the cost; (i.e. $\frac{\partial c}{\partial s_t} = 0$), then the user cost should increase at the rate of discount. If, however, as we assumed earlier, the cost of extraction is negatively related to the remaining stock (i.e. $\frac{\partial c}{\partial s_t} < 0$), then the undiscounted user cost must increase at a rate less than the discount rate. In that situation the rate of resource depletion will, naturally, be lower than when there is no stock effect on the cost of extraction. Other conditions to be satisfied are the resource constraints as shown below:

$$\frac{\partial L}{\partial \alpha_t} = 0 \text{ gives } s_{t+1} = s_t - q_t \qquad t=0,1,\ldots\ldots T-1, \tag{3.29}$$

$$s(1) = a \tag{3.30}$$

and

$$\frac{\partial L}{\partial \lambda_T} = 0 \text{ gives } \bar{s}_T = s_T \tag{3.31}$$

The optimal resource use described above can also be analyzed by the optimal control theory in a continuous-time framework. The objective function is to maximize the present value of stream of annual net benefits of a given resource stock over time. The annual net benefit is the difference between the annual returns and costs expressed as:

$$NB\,(t) = pq_t - c(q_t, s_t) \tag{3.32}$$

The constraints are the same as before but with continuous time periods. The maximization problem can be written as:

$$\text{Max } NB = \int_0^T \left[pq_t - c(q_t\,,\,s_t) \right] e^{-rt}\,dt \qquad (3.19)'$$

Subject to:

$$\dot{s} = \frac{d\,s_t}{dt} = -\,q_t \qquad (3.20)'$$

$$s(0) = a \qquad (3.21)'$$

$$s_T = \bar{s}_T \qquad (3.22)'$$

The undiscounted Hamiltonian function is given by the following:

$$H = p\,q_t - c(q_t, s_t) - \lambda_t q_t \tag{3.23'}$$

The Hamiltonian function consists of two components: the current stream of net benefits and the loss of future income caused by the extraction of a unit of resources at the current period. The control variable is q_t, the state variable is s_t, and the co-state variable is λ_t.

According to the maximum principle of the optimal control theory, the maximization problem given in equations (3.19)′ to (3.22)′ can be solved by differentiating the Hamiltonian function with respect to the state variable, the control variable and the co-state variable and equating them to zero. The first order conditions for a local maximum are given below:

$$\frac{\partial H}{\partial q_t} = p(q_t) - \frac{\partial c}{\partial q_t} - \lambda_t \equiv 0 \tag{3.24'}$$

$$\frac{-\,\partial H}{\partial s_t} = \dot{\lambda} \equiv \frac{d\lambda_t}{dt} \tag{3.26'}$$

and

$$\frac{\partial H}{\partial \lambda_t} = 0\text{, which yields } \dot{s} - q_t = 0 \tag{3.29'}$$

Condition (3.26)′ can be further simplified. Let us assume that $\tilde{H}$ is a discounted Hamiltonian, then we have:

$$\tilde{H} = e^{-rt} H = e^{-rt}\left[\,p q_t - c(q_t, s_t)\,\right] - \alpha_t q_t$$

where $\alpha_t = e^{-rt}\lambda_t$ or $\lambda_t = e^{rt}\alpha_t$

Then we can write:

$$\frac{d\lambda}{dt} = re^{rt}\alpha_t + e^{rt}\frac{d\alpha}{dt}$$

$$\dot{\lambda} = r\lambda_t + e^{rt}\,\dot{\alpha}$$

by substituting $\dot{\alpha}$ (where $\dot{\alpha} = \frac{\partial \tilde{H}}{\partial s_t}$, analogous to (3.26)$'$)we get:

$$\dot{\lambda} = r\lambda_t - e^{rt}\,\frac{\partial \tilde{H}}{\partial s_t}$$

Then recognizing that $\frac{\partial \tilde{H}}{\partial s_t} = -e^{-rt}\,\frac{\partial c}{\partial s_t}$

and substituting it we obtain:

$$\dot{\lambda} = r\lambda_t + \frac{\partial c}{\partial s_t} \qquad (3.28)'$$

Condition (3.24)$'$ states that the optimal schedule of resource extraction is one in which the net benefit from the marginal unit extracted is equal to the user cost at each time period. While condition (3.29)$'$ requires that the rate of extraction should satisfy the changes in resource stock over time as determined by the equation of motion (3.20)$'$. Condition (3.28)$'$ is the same as condition (3.28) of the discrete time model and it states that the user cost of a unit of resource in the ground should grow at the discount rate plus the effect of the depletion of the stock on the cost of extraction.

CHAPTER IV

A DYNAMIC ECONOMIC MODEL OF SOIL CONSERVATION

Purpose of the Chapter

The purpose of this chapter is to develop a general dynamic optimization model of soil conservation and derive necessary conditions for an optimal sequence of decisions (or optimal policy) of soil resource use for a private decision maker. The central question is whether the benefits from maintaining soil productivity by using soil conserving practices provide enough incentives to persuade farmers to adopt those practices. Only if the discounted benefits more than offset the discounted costs of employing conservation practices can farmers be persuaded. The benefits and costs of selected conservation practices will be analyzed by using a dynamic optimization model for soil conservation.

A discrete time model which employs the Lagrangian technique is presented in the next section. Then an optimal control continuous-time model is formulated and the optimal paths for soil erosion, input use, investment in conservation capital, and the implicit cost of soil loss (or user cost) are derived. In both models, however, the choice variables are assumed to be continuous and all functions are assumed to be differentiable.

Although, in many circumstances farmers face discrete decision choices, researchers have often approximated those discrete decision choices by formulating a continuous variable to satisfy the differentiability assumption. For example, Burt (1981) used the percentage of the acreage devoted to wheat, while Segarra (1986) used the percentage of the land in a particular rotation as a decision variable. Later in this chapter, a dynamic model with a discrete choice variable and it's empirical application will be discussed.

Overview of Soil Conservation Models

Producers who are concerned with long term profitability must consider both the near term benefits and the long term consequences of their production decisions. Consider the choice between two tillage systems. One system has low operating cost but allows more soil erosion than the second. The first system may have a higher near term profit while the second system may be more profitable in the future. The best system for a producer is influenced by the technical and economic relationships among annual soil loss, initial soil depth, crop yields, prices, production cost, discount rates, and ownership. McConnell (1983) states that there are many circumstances under which well informed producers will delay adoption of conservation practices and incur soil loss over time.

The sequence of production decisions which maximizes the net present value of returns from a specific farm can be estimated given assumptions about productivity, future discount rates, prices, costs and technological improvements. The question is whether such an erosion rate determined in a profit maximizing frame work is socially optimal. If there were no off-site damages from soil erosion, the rate of soil loss allowed by private farm operators would be socially optimal if the private discount rate were equal to the social discount rate and if the land market accurately reflected the value of productivity lost from soil erosion. While the private discount rate is determined by the capital market, the social discount rate is also a measure of society's concern about the welfare of future generations (McConnell, 1983). Because off-site damages from soil erosion are important (Clark et al., 1985) the social rate of erosion, however, would have to consider the off-site damage.

In the literature several approaches have been taken to model the optimal soil use over time and to determine optimal time to accept conservation practices. Walker (1982) introduced an Erosion Damage Function that measures the economic consequences from using an erosive practice instead of a conservation practice. Walker compared the net benefits from a conservation practice adopted in year t and used continuously until the end of the planning horizon with the net benefits from using the conventional practice in year t and then switching to conservation practice in year t+1.

Pagoulatos and Associates (1989) latter expanded the damage function concept, and included the benefits from using the conventional tillage system by delaying the adoption of conservation tillage for more than one period. Although the damage function approach sheds light on the relative profitability of conventional and conservation practices and on the time to switching from conventional to a conservation practice, it does not fully address the dynamic decision problem required for long term planning of soil resource use.

Miranowski (1984) used a linear programming model to determine the choice of tillage practices and crop rotations by farm operators under conditions of soil loss and consider the productivity decline. He concluded that operators who maximize long-term net returns will adjust their management practices if they recognize the impacts of soil erosion on productivity.

McConnell presented a dynamic optimization model of long-term soil use. His model indicates conditions under which a rational decision maker may increase rates of soil erosion. The model also highlights when the private and social paths of soil erosion diverge.

Miranda (1992) analyzed nationwide bids from the first sign-up for the conservation reserve program to test the hypothesis that farmers consider long-term impacts of soil erosion on productivity. Miranda compared the opportunity cost of withdrawing land from production for 10 years, the operator's share of the establishment costs, and estimated productivity gains from reduced erosion. Miranda concluded that, with the exception of the corn belt, farmers did not respond to the productivity effects caused by the soil loss. Miranda attributed the lack of response to the lack of adequate information about the productivity effects of soil erosion, and concluded that additional educational programs were essential.

A Discrete-time Model

Let us assume that a producer has a single commodity production function $y(x_t, d_t)$, where x_t is a vector of productive inputs, such as labor, fertilizer, pesticides, and machinery used in time period t and d_t is the stock (depth) of soil available in period t. We may also assume that the first partial derivatives of the yield function with respect to x_t and d_t are positive. As the quantity of an input increases the output is expected to increase. An increase in the stock of soil also has a positive effect on output because soil holds nutrients and water vital to plant growth.

Let us also assume that the producer has a cost function denoted as $c(x_t, d_t)$ where x and d are as described earlier. The problem facing the producer is, therefore, to maximize the net present value of returns (V) from soil resources over a planning horizon subject to the changes in soil depth overtime determined by the equation of motion.

The maximization problem is presented as:

$$\text{Maximize } V = \sum_{t=1}^{T-1} \left[\frac{P \cdot y(x_t, d_t) - c(x_t, d_t)}{(1+r)^t}\right] + \frac{F(d_T)}{(1+r)^T} \tag{4.1}$$

$$\text{Subject to: } \quad d_{t+1} = d_t - f_t(x_t) \tag{4.2}$$

$$d(1) = \bar{d} \tag{4.3}$$

$$x_t \geq 0 \, , d_t > 0 \tag{4.4}$$

Where P is the price of the output, $f_t\ (x_t)$ is the function that determines the rate of change of soil depth which is a function of the inputs used, T is the length of the planning horizon, r is the private discount rate, and F is the final value of the land at the end of the planning horizon which is a function of the remaining soil depth at time T.

The problem described in equations (4.1) through (4.4) is a discrete-time control problem and necessary conditions can be derived by examining the first order conditions using the Kuhn-Tucker theorem. The state variable is the soil depth, d_t, and the control variable is the bundle of inputs used, x_t. We can gain important economic insights from the necessary conditions by setting up the Lagrangian function and taking it's partial derivatives with respect to the state variables, control variables and Lagrangian multipliers for all time periods. The Lagrangian function is given below:

$$L = \sum_{t=1}^{T-1} \left[\frac{Py(x_t, d_t) - c(x_t, d_t)}{(1+r)^t}\right] + \sum_{t=1}^{T-1} \alpha_t \left(d_t - d_{t+1} - f_t\ (x_t)\right) +$$

$$\frac{F(d_T)}{(1+r)^T} \tag{4.5}$$

The necessary conditions are:

1) $$\partial L/\partial x_t = \frac{P\frac{\partial y}{\partial x_t} - \frac{\partial c}{\partial x_t}}{(1+r)^t} - \alpha_t \frac{\partial f_t}{\partial x_t} = 0$$

or $$P \cdot \frac{\partial y}{\partial x_t} \cdot \frac{1}{(1+r)^t} = \frac{\partial c}{\partial x_t} \cdot \frac{1}{(1+r)^t} + \alpha_t \frac{\partial f}{\partial x_t}, \qquad t = 1, \ldots .T\text{-}1 \tag{4.6}$$

2) $$\partial L/\partial d_t = \frac{P\frac{\partial y}{\partial d_t} - \frac{\partial c}{\partial d_t}}{(1+r)^t} + \alpha_t - \alpha_{t-1} = 0, \qquad t = 1, \ldots .T\text{-}1 \tag{4.7}$$

To simplify equation (4.7) let $\lambda_t(1+r)^{-t} = \alpha_t$

where λ_t is the undiscounted Lagrangian multiplier, then by substituting λ_t in equation (4.7), multiplying $(1+r)^t$ to both sides of the resulting equation and arranging terms we get:

$$\lambda_t - \lambda_{t-1} = r\lambda_t - \left(P\frac{\partial y}{\partial d_t} - \frac{\partial c}{\partial d_t}\right), \qquad t = 1, \ldots .T\text{-}1 \tag{4.8}$$

3) $$\partial L/\partial \alpha_t = 0 \text{ gives } d_{t+1} - d_t = f_t(x_t) \tag{4.9}$$

4) $$d(1) = \bar{d} \tag{4.10}$$

and

6) $$\partial L/\partial x_T = -\alpha_T + \partial F/\partial x_T = 0$$

$$\text{or } \alpha_T = \partial F/\partial x_T \tag{4.11}$$

Before we explain the necessary conditions described in equations (4.6) through (4.11), let us explain the Lagrangian multiplier, α_t. The meaning of this variable can be interpreted from the Lagrangian by adding a constant, say b to the constraint (4.2) which then becomes $d_{t+1} = d_t - f_t(x_t) + b_t$. Then take the partial derivative of the Lagrangian with respect to b_t to get $\alpha_t = \partial L/\partial b_t$ Whittle (1982). The Lagrangian multiplier, α_t, therefore, measures how much the maximum value of the objective function would increase if the soil depth were increased by one unit at the end of t^{th} period. In other words, α_t measures the decline in the optimal present value of the objective function from the loss of a marginal unit of soil depth at time t+1. α_t is the marginal value of future production forgone or the marginal user cost as a result of a production decision at time t. That cost is measured by the forgone future profits if a unit of soil is eroded in the current period. So, in addition to the costs and returns of current production, the producer has to consider the impact of current input use on future returns.

The necessary condition for the optimal input use is found by solving equation (4.6). The condition states that inputs should be used in production until the value of the marginal product is equal to the marginal factor cost of the input plus the present value of any loss in future productivity due to soil depletion. If the current input use has no impact on the future soil depth then equation (4.6) becomes the classical static condition, that is optimal level of each input is where the value of the marginal product is equated with the input cost.

Equation (4.8) shows the behavior of the (undiscounted) marginal user cost along an optimal time path. The condition requires that the marginal user cost should grow at the rate of discount less the soil's contribution to the current profits. If a marginal change in the soil depth has no impact on current profits then the marginal user cost should grow at discount rate, which is merely considered as a capital gain (Fisher, 1981).

Equation (4.9) is simply a restatement of the difference equation for the soil depth and equation (4.10) is a restatement of the initial conditions on the state variable. Whereas, equation (4.11) defines the terminal value of the user cost (α_T).

This concludes the discussion of the simple dynamic discrete model of soil conservation. In the next section we will slightly expand the model by including a soil conservation capital and making instantaneous time changes.

A Continuous-Time Model

The discrete-time model can be modified by including a stock of soil conservation capital denoted as k_t, and a constraint describing the change of that stock over time depending upon the remaining stock and the amount invested in time t or I_t. By assuming that time is continuous i.e. $0 \leq t \leq T$, the model becomes a continuous-time model. In addition to the input levels, the new model will enable us to determine optimal levels of investment in soil conservation capital such as terraces.

Define the production function as $y(x_t, d_t, k_t)$, the cost function as $C(x_t, I_t)$, and the rate of change of conservation capital as $h_t(k_t, I_t)$. The returns function, assuming a constant price, is written as:

$$V_t(x_t, d_t, k_t, I_t, t) = P\ y(x_t, d_t, k_t) - C(x_t, I_t)$$

The maximization problem gets the form

$$\text{Maximize } J = \int_0^T V_t(x_t, d_t, k_t, I_t, t)\, e^{-rt}\, dt + F(d_{T+1}, k_{T+1})\, e^{-rT} \tag{4.13}$$

Subject to:

$$\dot{d} \equiv \frac{d\,d_t}{d\,t} = f(x_t, k_t) \tag{4.14}$$

$$\dot{k} \equiv \frac{d\,k_t}{d\,t} = h_t(k_t, l_t) \tag{4.15}$$

$$d(0) = \bar{d} \tag{4.16}$$

$$k(0) = \bar{k} \tag{4.17}$$

and $d \geq 0,\ x \geq 0,\ k \geq 0,\ l \geq 0.$

The Lagrangian function is:

$$L = \int_0^{T-1} \Big[V(\cdot)\, e^{-rt} + \alpha_t(\dot{d} - f(x_t, k_t)) + \mu_t(\dot{k} - h(k_t, l_t))\Big] dt$$

$$+ F(x_T, k_T)\, e^{-rT} \tag{4.18}$$

where $\dot{d}$ and $\dot{k}$ are the instantaneous changes in the state variable determined by the equations of motion in equations (4.14) and (4.15), respectively. Notice that the equations of motion are differential equations in the continuous-time model while they were difference equations in the discrete-time model. The parameters α_t and μ_t are the co-state variables similar to the Lagrangian multipliers in the discrete-time model. The initial stock of conservation capital is given, $\bar{k}$. There are two state variables; soil depth and stock of conservation capital, and two control variables rate of inputs used and rate of investment in erosion preventive capital.

The discounted Hamiltonian is defined as:

$$H(x_t, d_t, k_t, I_t, t) = V(x_t, d_t, k_t, t)\, e^{-rt} - \alpha_t f(x_t, k_t) - \mu_t h(k_t, I_t) \quad (4.19)$$

The Hamiltonian function is interpreted as the net rate of increase in the value of resource, and it consists of two components. The first component, which is the term V(•), represents the flow of current returns in instant t. The second component is the sum of the two terms $\alpha_t f_t(\bullet)$ and $\mu_t h_t(\bullet)$, which represent the change in the value of the stock of soil and the stock of conservation capital, respectively.

According to the maximum principle, the maximization problem described in equation (4.13) through (4.17) can be reduced to maximizing the Hamiltonian with respect to the control variables. In other words, the input levels and the rate of investment in soil conservation capital can be chosen so that the current flow of returns minus the future losses due to stock depletion is maximized in each instant. So, the task of optimizing a whole sequence is replaced by a sequence of "instantaneous" optimizations (Conrad and Clark, 1987, Whittle, 1982).

The necessary conditions can be derived by taking the first partial derivatives of the Hamiltonian with respect to the state variables, control variables, and the co-state variables. The two maximum conditions are:

1) $\dfrac{\partial H}{\partial x_t} = 0$

or $$(\partial V/\partial x_t)e^{-rt} = \alpha_t (\partial f/\partial x_t) \quad (4.20)$$

2) $\frac{\partial H}{\partial I_t} = 0$

or $(\partial V/\partial I_t)e^{-rt} = \mu_t (\partial h/\partial I_t)$

Assuming that $\partial h/\partial I_t = 1$, i.e. for every unit invested there is one unit increase in the stock of capital, and recognizing that I_t appears only in the cost part of the returns function, V(•), we have:

$$(\partial c/\partial I_t)e^{-rt} = \mu_t \qquad (4.21)$$

The adjoint equations are:

1) $$-\frac{\partial H}{\partial d_t} = \frac{d\,\alpha_t}{dt} \qquad (4.22)$$

2) $$-\frac{\partial H}{\partial k_t} = \frac{d\,\mu_t}{dt} \qquad (4.23)$$

we know that $H = V(\bullet)e^{-rt} - \alpha_t f_t(\bullet) - \mu_t h_t(\bullet)$.

Let $\alpha_t = \lambda_t e^{-rt}$ or $\lambda_t = \alpha_t e^{rt}$

and $\mu_t = \beta_t e^{-rt}$ or $\beta_t = \mu_t e^{rt}$

we can write equation (4.22) as:

$$\frac{d\alpha_t}{d_t} = -\frac{\partial H}{\partial d_t} = -\frac{\partial V}{\partial d_t}e^{-rt} + \alpha_t \frac{\partial f(\bullet)}{\partial d_t}$$

But $\dot{\lambda} = r e^{rt}\alpha_t + e^{rt}\frac{d\,\alpha_t}{dt}$

Substitute α_t and $\frac{d\alpha_t}{dt}$ and obtain:

$$\dot{\lambda} = r\lambda_t + e^{rt}\left[-\frac{\partial V}{\partial d_t}e^{-rt} + \alpha_t \frac{\partial f}{\partial d_t}\right]$$

Since $\frac{\partial f}{\partial d_t} = 0$ we have

$$\dot{\lambda} = r\lambda_t - \frac{\partial V(\bullet)}{\partial d_t} \tag{4.24}$$

Similarly equation (4.23) can be written as:

$$\frac{d\,\beta_t}{dt} = r\,\beta_t - \frac{\partial V}{\partial k_t} + u_t\frac{\partial f_t}{\partial k_t} + \beta_t\frac{\partial h_t}{\partial k_t} \tag{4.25}$$

Assume that $\partial V/\partial k_t = 0$ and $\frac{\partial h}{\partial k_t} = \delta$ then we have:

$$\text{or} \quad \frac{d\,\beta_t}{dt} = (r+\delta)\,\beta_t + u_t\,\frac{\partial f}{\partial k_t} \tag{4.26}$$

The first partial derivatives of the Hamiltonian with respect to co-state variables are:

$$\frac{-\partial H}{\partial \alpha_t} = \frac{d\,d_t}{dt} = f_t(x_t,k_t) \tag{4.27}$$

$$\text{and} \quad \frac{-\partial H}{\partial \mu_t} = \frac{d\,k_t}{dt} = h_t(k_t,I_t) \tag{4.28}$$

Finally, the transversality conditions are:

$$\alpha_T = \frac{\partial F}{\partial d_T} \tag{4.29}$$

$$\mu_T = \frac{\partial F}{\partial k_T} \tag{4.30}$$

Equation (4.20) is comparable with equation (4.6) of the discrete time model and needs no further explanation. While equation (4.21) states the condition for optimal level of investment in erosion preventive capital. The condition requires that the present value of marginal cost of the investment in conservation capital be equal to its user cost. The user cost (μ_t) is defined as the present value of the amount that the objective function value declines due to a unit deterioration in the stock of conservation capital.

The adjoint equations give conditions (4.22) and (4.23). Equation (4.24) is analogous to equation (4.8) of the discrete-time model. Whereas equation (4.25) requires that the implicit cost of conservation capital or its marginal value should grow at the rate of discount plus the impact of the change of conservation capital on the marginal user cost of soil and the marginal user cost of stock of conservation capital minus the conservation capital's contribution to the current returns. Assume that conservation capital is not explicitly in the yield function and that δ is a factor of physical deterioration of that capital. Then equation (4.26) implies that user cost of conservation capital should grow at the discount rate plus the rate of physical deterioration of capital plus the impact of the stock of capital on the marginal user cost of soil erosion.

The optimal paths of the control variables should also satisfy the stock constraints given in equation (4.27) and (4.28) and the transversality conditions stated in equations (4.29) and (4.30). In the next sections we will describe a discrete model of soil conservation with a discrete decision variable.

A Discrete Decision Model

So far we have discussed two dynamic economic models of soil conservation, one in discrete-time and the other in continuous-time framework.

In those models it was assumed that the decision variables are continuous. Nevertheless, farmers often face alternative choices and a discrete model would more closely represent farmer's situation. By using a discrete decision model benefits and costs associated with alternative choices can be compared. In this example the decision variables are tillage systems. Let us assume that the farm operator knows the effect of soil erosion on future returns and farm sale value at the end of the planning horizon. The operator, therefore, maximizes the present value of current returns plus present value of future returns. If the capital markets are working efficiently, then the future farm sale can be approximated by assuming a sufficiently long planning horizon. The farmer's objective function can, therefore, be represented by the following equation.

$$\text{Maximize } V = \sum_{t=1}^{T} \sum_{i=1}^{I} \left[Py(x_{t,i}, d_t, g_t) - w_{t,i}\, x_{t,i} \right] \frac{1}{(1+r)^t} \qquad (4.31)$$

Subject to:

$$d_{t+1} = d_t - f(x_{t,i}) \qquad (4.32)$$

$$d(1) = \bar{d} \qquad (4.33)$$

Where i is index of the tillage system used, t is time period, y(.) is the yield for tillage system i at time t which is a function of a vector of inputs (x) and the remaining soil depth (d). The variable g is the rate of technological improvement, P is the price of the commodity, w is the per unit cost of inputs, r is the interest rate and $f(x_{t,i})$ is the eroded soil depth in time period t when i^{th} tillage system is used. In order to derive an optimal path of erosion rates in a discrete decision model the following condition must hold.

The condition for an optimal discrete choice states that tillage system (j) will be selected in time period t If the present value of its net current benefits less the present value of net benefits from any other tillage system is greater than the total user cost of the soil erosion.

To express the above condition algebraically let j be a more erosive tillage system which has lower operating costs or higher yields, and as a result has a greater current return. Let i be a more conservative system that yields lower current annual returns but also allows less erosion. The tillage system chosen now will affect current returns as well as future returns. The dynamically optimal sequence of tillage systems for all future periods depends upon the action taken at the current period because that determines the remaining depth for future periods. The total user cost of soil erosion when crop management system j is chosen in period t is the present value of future returns of an optimal sequence of choices from time t+1 to the end of the planning horizon less the present value of future returns of an optimal sequence of choices from t+1 to the end of the planning horizon when alternative i is adopted in period t. The condition then states that the erosive alternative will be adopted if its greater returns more than offset the total user cost (TUC) of soil erosion. The condition can be expressed as:

$$[P_t y_{t,j}(x_{t,j}, d_t, g_t) - w_{t,j} x_j] - [P_t y_{t,i}(x_{t,i}, d_t, g_t) - w_{t,i} x_{t,i}] \leq \frac{TUC^*_{tj}}{(1+r)^t} =$$

$$\left\{ \sum_{n=t+1}^{T} \frac{[P_n y^*(z_n, d_n, g_n) - w_n x_n]}{(1+r)^n} \Bigg|_{ti} - \sum_{n=t+1}^{T-1} \frac{[P_n y^*(x_n, d_n, g_n) - w_n x_n]}{(1+r)^n} \Bigg|_{tj} \right\} \frac{1}{(1+r)^t} \qquad (4.34)$$

where n denotes time periods after t, * indicates that the optimal sequence of tillage systems were used after period t, and the subscripts ti and tj under the present value of optimal future returns indicate that optimal future choices are conditional on the choice made in period t, all other terms are as defined earlier.[3]

3 A discrete-decision model similar to this model was discussed by Hertzler et al. (1985).

The farmer's decision, therefore, depends upon a whole array of factors that affect both the left hand side as well as the right hand side of equation (4.34). The left hand-side is affected by the differential costs in operating inputs and differential yields among different tillage systems. Anything that increases the current returns of the conservation tillage or reduces the current returns of conventional tillage will favor the adoption of conservation tillage systems, and vice versa. If the cost of acquiring new equipment or learning a new management system is significant conservation tillage becomes less competitive.

The right hand side depends on the discount rate, technological improvement, price expectations, and the impact of soil erosion on productivity. If the difference between the two terms on the right hand side were zero, it would imply that the greater soil loss resulting form using a conventional tillage system was exactly offset by the higher cost of the conservation tillage system. The farmer would, therefore, choose the tillage system that gives higher current net returns. One reason for such an outcome is the inherent characteristics of the soil under consideration. As discussed in chapter 2, some deep, fertile soils that have high tolerance levels for soil erosion, will not show any significant yield decline for relatively longer periods of time. The length of the analysis period is also important. The longer the period the greater the erosion's effect and the greater the damage. Higher discount rates also reduce the present value of future returns thus reducing the importance of the user cost in the farmer's decision. Conversely, low discount rates, high future price expectations and high technological advance will increase the right hand side value, thus making user cost an important element in farmer's choice between tillage systems. For example if technological advance is considered and the technology is assumed to be multiplicative in the yield-soil depth response function there would be a greater absolute increment of yield on the deeper soil (Young, et al., 1985) and that would increase the yield loss damage. In a discrete decision model the optimal path of erosion rates is not smooth as in the case of continuous model. We will now turn to the empirical models. The general format of the empirical models estimated in this dissertation is introduced in the following section.

The Empirical Model

A dynamic discrete decision model was developed for the empirical estimation.

Model specification

The description of the model is given below:

$$\text{Max } V =$$

$$\sum_{n=1}^{N}\left[\left(\sum_{i=1}^{I}\left\{\sum_{s=1}^{S}\left[\sum_{t=1}^{10}(P \cdot Y_{s,t,i} - vc_i)(1+r)^{-t}\right] \cdot AC_s\right\} - FC_i\right) + \left\{\sum_{t=1}^{10}\left(PP \cdot AP_{s,t}\right) \cdot \left(1+r\right)^{-t}\right\}\right]\left(\frac{1}{1+r}\right)^{10(n-1)} \tag{4.35}$$

Subject to:

$$AC_{s,t} + AP_{s,t} \leq \overline{T}A(s,t) \tag{4.36}$$

$$\sum_{s=1}^{S} \overline{T}A(s,t) \leq 600 \tag{4.37}$$

$$D_{s,t+1} = D_{s,t} - f_s(x_{,t,i}) \tag{4.38}$$

$$D_{s,0} = \overline{D}_{s,0} \tag{4.39}$$

The Mitcherlich-Spillman function combines a non linear yield plateau with a multiplicative exponential growth term:

$$Y_{st} = \left[A_s - B_s \bullet EXP\ (R_s \bullet D_{st})\ \right] \bullet EXP(b.t) \tag{4.40}$$

The production function and its estimation will be discussed in Chapter 5. Abbreviations used in the model are as follows:

$n = 0,1, \ldots 15$	is the number of discrete investment or decision periods.
$t = 1,2, \ldots 10$	is the number of years in each investment or decision period.
$i = 1,2, \ldots I$	is the number of alternative tillage systems.
$s = 1,2, \ldots S$	is the number of soil types in the farm.
P	is the price of wheat in dollars per bushel.
PP	is the pasture returns in dollars per acre.
$Y_{s,t,i}$	is the yield of wheat for soil type s in time t, with tillage system i.
A_s, B_s, R_s	are the Spillman yield function parameters estimated for soil type s.
VC_i	is variable cost for tillage i
FC_i	is the total farm machinery investment cost required by tillage system i for each diversion period.
AC_s	is the cultivated acreage of soil type s.
$AP_{s,t}$	is the acreage in pasture of soil type s
$\overline{T}A(s,t)$	is the total acreage of soil type s in the farm
r	is the discount rate
$D_{s,t}$	is the depth of soil type s, in time t.

$f_s(x_{t,i})$ is the eroded depth of soil type s in time t when i^{th} tillage system is used

b is the rate of yield growth due to technological progress.

The objective in equation 4.35 is to maximize the present value of returns from a 600 acre farm consisting of S soil types by choosing an optimal sequence of wheat tillage systems and/or pasture for 150 year period. This can more practically be conceived of as consisting of a 50 year planning horizon plus an additional 100 year period which is used to approximate the sale value of the farm after the first 50 years. It is assumed that the tillage systems are replaced every 10 years. Thus, the part within the inner summation sign is the total present value of the returns over the variable costs per acre when tillage i is selected for that period. The per acre returns are multiplied by the acres of each soil, summed over each soil type and discounted. The total machinery investment cost required by i^{th} tillage system (FCi) is subtracted to get the present value of net returns of the farm for investment period n when tillage system i is used. The dynamic discrete decision problem is to find the sequence of tillage systems or pasture which maximizes the net present value of the farm's resources.

The constraints of the model are given by equations (4.36) through (4.39). Constraint (4.36) states that the total acreage of each soil type, $\overline{T}A(s)$ is the sum of the tilled acreage and the acreage used for pasture. Assuming no setaside requirements, constraint (4.36) implies that all acres will be either cultivated or returned to pasture and one tillage system is used for the whole farm. Constraint (4.37) gives the limit on the total farm area and constraint (4.38) is the soil depth transition equation for soil type s. Finally, the initial soil depth for soil type s is given by constraint (4.39). These constraints should hold for all time periods. In the next chapter we will discuss the data required to solve this model and methods used to generate data.

CHAPTER V

DATA REQUIREMENTS AND SIMULATION

Data Requirements

The main types of data needed were crop budgets for the tillage systems used for wheat production in the study area, the impact of each tillage system on soil loss and an estimate of a function describing the yield-soil depth relationship. It was also necessary to have information about the soil profile of representative farms. All the data are soil specific. The procedures used to generate these data are described in the next sections.

Erosion Rates in Grant County

Table 5.1 summarizes the information from the 1982 National Resources Inventory (NRI) crop use for Grant County. The NRI survey indicated that average erosion rates were 2.7 tons per acre on all 1984 cropland. Appearances would indicate that soil erosion is not a major problem; however, more than 80,000 acres (over 17 percent of all cropland) have an erodibility index for wind or water erosion which is greater than 8. The erodibility index is a measure of the rate at which a completely bare field would erode relative to the tolerance (T) value or rate at which soil is renewed. An erodibility index of 8 means the soil could potentially erode at a rate 8 times the rate at which it is renewed.

TABLE 5.1

SUMMARY OF TOTAL CROP LAND, HIGHLY ERODIBLE CROP LAND AND AVERAGE RATE OF SHEET, RILL AND WIND EROSION ON CROP LAND IN THE GRANT COUNTY STUDY AREA IN 1982

Category	Total Acres	Land in Crops	Close Growing Crops**	Erosion Per Year Total	Rate	HEL*** Cropland
		(thos.acres)		(thos. tons)	(tons/ac)	(thos.acres)
Total	617.4	461.4	441.5	1263.9	2.7	80.3
I all	128.5	128.5	110.8	199.8	1.7	0.0
II all	190.6	164.1	156.6	426.4	2.6	0.0
II e	62.8	49.1	45.0	176.7	3.60	
III all	177.3	139.0	138.2	423.5	3.0	23.5
III e	141.5	110.7	110.7	365.4	3.3	19.3
IV e all	63.4	34.2	33.4	203.2	5.9	47.8
IV e	48.4	30.8	30.0	190.5	6.2	45.5
V	11.8	0.8	0.8	1.0	1.3	6.1
VI all	41.7	1.7	1.7	8.2	4.8	0.1
VI e	40.0	1.7	1.7	8.2	4.8	0.1

* Source: Soil Conservation Service, "Grant County Oklahoma Resource Inventory: 1982 NRI; Statistical Tables".

** Includes wheat, barley and oats.

*** Calculated from geographical data base for Grant County.

Tillage Systems

Epplin et al. (1983) examined twelve tillage systems for wheat production in Oklahoma. Four tillage systems were selected from those systems for this study. The four systems were plow (PL), disk chisel (DC), sweep twice (SWP2), sweep once (SWP1). The major differences among the systems were the number of tillage operations and the types and amounts of chemical application. Dates of planting, harvesting, and fertilizer applications were assumed to be the same for each system.

The plow system (PL) consisted of a disk operation immediately after the harvest. The land was then tilled with a moldboard plow. A second disk operation was assumed to follow in August. A field cultivator was used to apply fertilizer.

The disk chisel (DC) system consisted of a disk operation after harvest followed by one chisel operation in July and another in August. Fertilizer was applied in late August with a field cultivator.

The SWP2 system was assumed to consist of two V-blade sweep operations, one in June after harvest and a second in August. A herbicide application of three-eighths of a pint of Sencor and one-half pint of Roundup per acre were used with second tillage operation. Anhydrous ammonia was also applied with same operation.

The SWP1 system consisted of only one V-blade sweep operation combined with anhydrous ammonia. Post-harvest herbicides of Bladex and Atrazine were applied. Pasture was also included in the systems so that operators can rent their land for pasture if that was more profitable than wheat for any soil map unit.

Analysis of continuous wheat was chosen because it is the major practice in the wheat growing counties. For example 81 percent of the wheat planted in 1988 in Oklahoma was wheat after wheat compared to 45 percent in Texas and 28 percent in Kansas (Daberkow and Gill, 1989).

Estimation of Budgets

A budget was estimated for each of the four tillage systems. The budgets were a modification of the Oklahoma State University (OSU) Enterprise Budget series nos. 761202101, 76370004, 76007101, and 76002601 for PL, DC, SWP2, and SWP1, respectively. These budgets were developed by using the OSU Budget Generator (Kletke, 1979). The budgeted costs for each system shown in Table 5.2 are based on 1990 prices. The annual variable costs were greatest for the reduced tillage (SWP2 and SWP1) systems because the greater use of herbicide for effective weed control, more than offset the lower costs for fuel, repair and labor.

The timeliness and efficiency of the machinery complements were tested by a Machinery Selection Program (Kletke and Sestak, 1991). Machinery ownership costs are the sum of depreciation, interest, and taxes. The ownership costs for the reduced tillage systems were lower than the conventional tillage systems. The SWP2 and SWP1 systems required lower machinery investment cost than disk chisel by 6% and 10%, respectively. The plow system required the greatest machinery investment. The total production costs for the SWP2 and SWP1 systems were greater than the total costs of DC system by about 9% and 20%, respectively. The total cost of the plow system falls in between.

Currently the DC has the lowest total cost, but it has a higher erosion rate than the sweep systems although less than with the moldboard plow. Later in the analysis it will be examined whether the higher current returns from DC system will be offset by reduced long term soil erosion cost. If that should be the case, sweep systems will be included in an optimal plan. Such an analysis

TABLE 5.2

COST OF PRODUCTION BUDGETS FOR WHEAT FOR ALTERNATIVE TILLAGE SYSTEMS USED IN THE STUDY

	Unit	Cost or Price	Enterprise Budgets for Different Systems: Quantity of Inputs				Value			
			Plow	DiskChis	SwpTwice	SwpOnce	Plow	DiskChis	SwpTwice	SwpOnce
WHEAT SEED	BU	4.50	1.00	1.00	1.00	1.00	4.50	4.50	4.50	4.50
18-46-0 FERT.	CWT	11.00	1.00	1.00	1.00	1.00	11.00	11.00	11.00	11.00
ANHYD.AMMON.	LBS	0.11	54.00	54.00	54.00	54.00	5.94	5.94	5.94	5.94
INSECT.(PARATH.)	OZ	0.17	5.00	5.00	5.00	5.00	0.86	0.86	0.86	0.86
GLEAN	OZ	17.17	0.08	0.08			1.42	1.42	0.00	0.00
ATRAZINE	LBS	2.00				0.50	0.00	0.00	0.00	1.00
METRIBUZIN	PTS	14.91			0.57	0.57	0.00	0.00	8.50	8.50
2-4,D	GAL	10.80			0.50	0.50	0.00	0.00	5.40	5.40
BLADEX	LBS	3.88			0.00	2.50	0.00	0.00	0.00	9.70
ROUNDUP	PTS	8.75			0.50	0.50	0.00	0.00	4.38	4.38
SEED TREATMENT	BU	0.60			1.00	1.00	0.00	0.00	0.60	0.60
CUSTOM HARV.	ACR	15.00	1.00	1.00	1.00	1.00	15.00	15.00	15.00	15.00
LABOR CHARGES	HR	4.50	1.61	1.60	1.11	1.07	7.25	7.20	5.00	4.82
REP.,LUB.,FUEL							18.71	16.74	10.29	9.90
ANN.OPER.CAPITAL		$ 0.12					3.72	3.48	4.19	4.39
TOTAL OPERATING COSTS							68.40	66.14	75.65	85.98
FIXED COSTS:										
INTEREST PAYMENTS							11.19	10.32	9.62	9.26
DEP.,INSUR.,&TAX							11.96	10.62	10.00	9.58
TOTAL FIXED COSTS							23.15	20.94	19.62	18.84
TOTAL FIXED & VARIABLE COSTS							91.55	87.08	95.27	104.82

* Costs are in 1992 dollars.

Abbreviations Used

Disk Chis. = Disk Chisel tillage system, SwpTwice = Tillage system with two sweeptillage operations.
Swp Once = Tillage system with only one sweep tillage operation.
Parath = Parathion.

required estimates of the expected soil erosion under Grant county weather conditions and a measure of its impact on soil productivity for all soils in the county. For that purpose a simulation model is employed which will be discussed in the next section.

Simulation of Yield and Erosion Rates

The necessary information involved estimates of the expected yield and soil loss for each soil type. In the context of an experimental design, the factors were soil type X tillage system X slope X soil depth X slope length. The Erosion-Productivity Impact Calculator or EPIC Model (Williams et al., 1983) was used to simulate the wheat yield and rate of soil erosion for each soil map unit under conventional tillage, disk chisel and sweep tillage systems over a 150-year period. EPIC is a physically based model which operates on a daily time step to continuously simulate the processes associated with erosion and determine the relationship between soil erosion and soil productivity for various agricultural management practices (Williams, et al.,.1983). A detailed description of the EPIC components and the mathematical relationships used is given by Sharpley and Williams (1990).

The purpose of the simulation was to generate replicated yields and erosion rates for each tillage system over a planning period used in the study. EPIC generates daily stochastic estimates of yield and erosion rates for each tillage system for a given soil point. Because of the stochastic weather factor, the simulated data showed great variability. To determine the expected crop yield for a given soil depth ten replications were generated for each tillage system. EPIC produced yields and erosion rates for each replication using a random number that triggers EPIC to generate a unique weather pattern for each run.

The EPIC model requires data which include soil profile characteristics, topographic factors (slope and slope-length), weather (temperatures, rainfall, and wind), soil conservation structures (such as terraces), and crop management data (including tillage, crop, inputs, and dates of field operations). A soil or a soil series has a specific topographic and soil profile characteristics. A soil map unit may consist of many different soils. Any estimate of yields or returns for a soil map unit must be a weighted average of the yields and returns of the different soils. For this analysis the soil profile data were obtained from the Soils-5 data base (the data base was created and maintained by the USDA-SCS at Ames, Iowa) which contains the profile characteristics of the major soils found in Grant county. The range of slopes and the soil depth used in the simulation were obtained from the soil survey of Grant County (USDA,SCS, 1985). The soil survey provides a range of slopes for each soil. The two extreme points of the slope range were selected for each soil. The slope-length was obtained from the Oklahoma SCS technical staff in Stillwater (Vaughn, 1992). Like the slope data, the slope-length data were a range of values within which the slope-length of a soil type was expected to fall. The midpoint slope-length was selected for the simulation. The information on crop management and timing of field operations were taken from the prepared budgets. Finally, there was no information available about the conservation structures, such as terraces, and no such structures were included in the simulation.

Selection of Production Function

A reliable yield-soil depth relationship is essential for any economic analysis of soil erosion. The importance of that relationship was emphasized by Crosson and Stout (1982) by stating that "We need empirically estimated curves relating erosion, or soil depth to yields on all the major soils in all the major crop-production regions". The importance of the soil erosion problem was discussed in chapter 2. Herein we are solely focussing on the estimation of a yield function. Hoag and Young (1983) pointed out that the criterion for a yield-topsoil depth function are that the function must have a non zero intercept, a non negative and diminishing marginal returns to topsoil, and that yield has to asymptotically approach a maximum attainable level which corresponds to the yield attainable at the ideal conditions and full topsoil depth. One of many such functions is the Mitcherlich-Spillman (M-S) function expressed as:

$$Y = A + B\,(1 - \mathrm{EXP}(r \cdot x))\,, \tag{5.1}$$

where A is the yield attainable at zero topsoil depth, B is a maximum yield increment from topsoil, r is the log of the ratio of successive marginal products, and x is the topsoil depth. The ratio of successive marginal products lies between zero and one given the assumptions of the study. The M-S function is often used in economic studies of soil erosion (Taylor 1982, Young et al. 1985, Hoag and Young 1983, Walker 1982, Christensen and McElyee 1985). Christensen and McElyee examined two different functional forms of M-S function and their implications on the economic analysis of soil conservation. Pagoulatos (1989) used a logistic growth rate model, which is consistent with the Hoag and Young agronomic criterion, to estimate yield as a function of topsoil depth and precipitation. Other studies used arbitrary rates of yield declines as topsoil is depleted (Miranowski 1984, Prato 1985).

In those studies topsoil depth was used as proxy for soil depth. That is because the top 20 cm is the primary rooting zone for most agricultural crops (Thomas, et al. 1989). However, in this dissertation the soil profile depth rather than topsoil depth was used to estimate the effect of erosion on wheat yields. There were two reasons for this. First, the characteristics of underlying horizons are important in determining crop yields. This has been pointed out by many researchers (Thomas, et al. 1989, Pierce et al. 1984, Adams 1949, Power, et al. 1981, Olson 1990, Shuman, et al. 1981, and Larson, et al., 1983). The underlying layers are particularly important in a long term analysis because as topsoil erodes lower layers are mixed within the rooting zone by the mechanical tillage thus altering the topsoil characteristics (such as clay and organic matter contents, change in structure, etc.) which may change available-water holding capacity of the soil and, hence, affect crop yields (Schertz et al., 1989). Secondly, EPIC simulates mixing of lower and top layers by tillage operations as the topsoil erodes to determine the characteristics of the rooting zone which determines crop yields. One concern of farming the subsoils, as pointed out by Miranowski (1984), is that organic matter content of subsoils is significantly lower than that of the topsoil. But the National Research Council (p. 132) states that "organic matter content of soil can be increased in relatively short periods of time under proper management practices, with beneficial effects on soil productivity". In any case, soil depth was selected as the explanatory variable in the yield function because of its importance in water-holding capacity and because of the need to examine the prospect of farming the subsoils some time in the future if soil loss continuously exceeds its natural rate of replenishment.

Estimation of the Yield Functions

Before the simulated data are used for estimating a yield function there are two properties of the simulated data that need to be addressed. First, the stochastic disturbances of the replicated data generated for different tillage systems from a single soil point are expected to be cross-sectionally correlated. Secondly, disturbances of the simulated time-series data are expected to be autoregressive. These two problems determined the selection of the estimation procedure.

The Cross-sectionally Correlated and Timewise Autoregressive model was used to estimate the yield function from the simulated data described above. Kmenta (1986, pp. 622-25) explains the model and shows procedures to transform the data for Generalized Least Square (GLS) method and obtain asymptotically efficient estimates of regression coefficients and their variances.

The Mitcherlich-Spillman function normally requires non linear estimation techniques. To use the linear GLS method the data were transformed. The following log-linear form was obtained:

$$Ln(M - Y) = Ln(B) + ln(r)\,x\,, \tag{5.2}$$

where M is the maximum asymptotically obtainable yield as soil depth is increased. Ethridge (1963) suggested that a good estimate of M could be obtained by graphically analyzing the yield data. However, EPIC simulated yields are stochastic. While on the average it generates values close to the predicted ones, a single-year simulated value could be either very high or very low compared to the average. The maximum yield value found in the simulated data was 6 Mt/ha (89 bu/acre), and that value was assigned to M. Having assigned a value to M it was straight forward to estimate equation (5.2) using the cross-sectionally correlated and time-wise autoregressive regression technique.

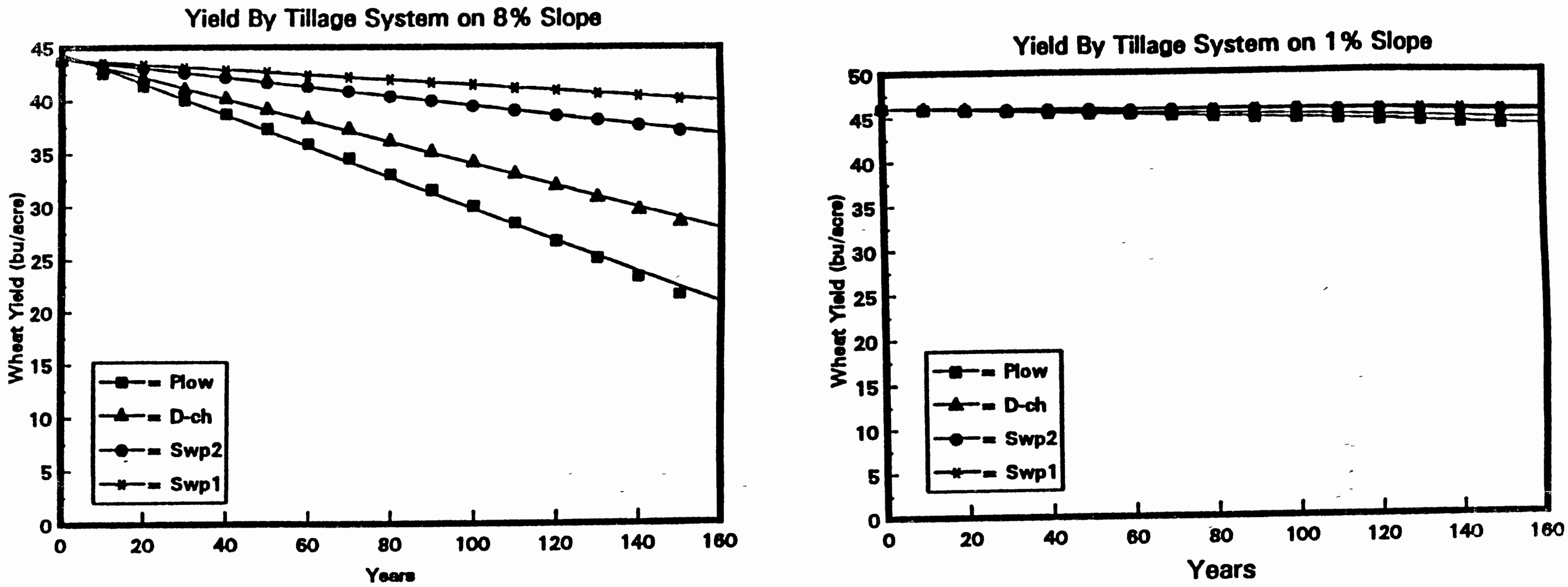
The data (yields and erosion rates) from 10 replications for each of the 4 tillage systems over a 150 year simulation period were pooled and arranged so that all observations of a cross-sectional unit are together. Here a cross-sectional unit is the tillage system. Three dummy variables were included in the model to determine if there were significant difference in simulated yields by tillage systems. The SHAZAM (White et al., 1990) program was used to estimate the regression. SHAZAM modifies the Kmenta procedure to keep the first observations. There were no significant differences in estimates of wheat yields among tillage systems. The estimated intercept term Ln(B) and coefficients of soil depth Ln(r) and their standard errors for the major soils in Grant county are presented in Appendix A. The estimated coefficients were significant and had the expected sign. The coefficients B and r of equation (5.1) and other soil properties by slope and land capability classes are given in Table 5.3.

The projected effect of the tillage system and accumulated soil erosion is illustrated in Figure 5.1 for a Grant silt loam soil with one percent (class I) and eight percent (class VI e) slopes. There is very little difference in crop yields over time on the class I soil but the wheat yield under conventional tillage on the Class VI e soil is projected to decline from more than 40 bushels to approximately 25 bushels per acre after 150 years. The differences in wheat yields under conventional tillage are shown for soils from the four land capability classes in Figure 5.2.

TABLE 5.3

ESTIMATED MITCHERLICH-SPILLMAN FUNCTION COEFFICIENTS AND OTHER CHARACTERISTICS OF GRANT COUNTY SOILS

	Soil	Slope	Map Unit	LCC	B	r	Bulk Density	Depth in (M)
1	Attıca	0.01	2	II	8.44	0.67	1.500	1 905
2	Attica	0.03	2	II	8.43	0.67	1.500	1 905
3	Attica	0.05	3	III	8.43	0.67	1.500	1 905
4	Attıca	0.03	3	III	8 43	0.67	1.500	1.905
5	Dale	0.01	6	I	3.85	0.92	1.393	1.829
6	Dale	0 03	7	III	3.86	0 92	1.393	1 829
8	Dale	0.08	7	III	3 88	0.92	1.393	1 829
9	Goodnıght	0 08	12	VI	8.52	0.66	1.683	1 524
10	Grainola	0.01	15	III	5 80	0.65	1.443	0 635
11	Grainola	0.03	15	III	5.81	0.65	1 443	0 635
12	Grainola	0.03	16	IV	5.81	0.65	1 443	0 635
13	Graınola	0.05	16	IV	5.83	0.65	1.443	0 635
14	Grant	0.01	17	II	6 50	0.58	1.390	1 499
15	Grant	0.03	17	II	6.51	0.58	1.390	1 499
16	Grant	0.05	18	III	6.53	0.58	1.390	1 499
17	Grant	0 03	18	III	6.51	0.58	1.390	1 499
18	Grant	0.05	19	III	6.53	0.58	1.390	1.370
19	Grant	0.03	19	III	6.51	0 58	1.390	1.370
20	Kingfisher	0.08	20	IV	5.94	0 57	1.393	0.686
21	Grant	0.05	20	IV	6 53	0.58	1.390	1 270
22	Grant	0.05	21	IV	6.53	0.58	1.390	1 422
23	Kingfisher	0.08	21	IV	5.94	0.57	1.393	0.686
24	Grant	0.08	21	IV	6.55	0.58	1.390	1.422
25	Port Sil	0.05	22	VI	15.23	0.44	1.415	2.032
26	Grant Sıl	0.08	22	VI	6.55	0.58	1.397	1 143
27	Kingfisher	0 01	24	II	5.93	0.57	1 393	0 737
28	Kingfisher	0 03	25	III	5.93	0.57	1.393	0.737
29	Kingfisher	0.05	26	III	5.93	0.57	1.393	0.737
30	Kirkland	0 01	29	II	8.40	0.60	1 415	1 829
31	Kirkland	0.03	30	III	8.42	0.60	1.415	1.829
32	Port SICL	0.07	33	VI	10.12	0.40	1 450	1 346
33	Norge	0.03	36	III	6.38	0.70	1.393	1.524
34	Norge	0.05	37	III	6 39	0.70	1.393	1.524
35	Oscar SIL	0.07	38	V	4.24	0.98	1.454	1.930
36	PondCreek	0 01	39	I	6.26	0.72	1.393	1.829
37	PondCreek	0.03	40	II	6.29	0.72	1.393	1.829
38	Port	0.01	41	II	15.23	0 44	1.425	1.828
39	Pratt	0.05	43	IV	4.14	0 75	1 475	1.676
40	Pratt	0 03	43	IV	7.12	0.75	1.655	1.676
41	Quınlan	0.01	44	III	5.73	0.83	1.475	0 356
42	Quınlan	0.03	45	IV	5.73	0.83	1 518	0.356
43	Quınlan	0.05	45	IV	5 73	0.83	1.518	0 356
44	Woodward	0.08	45	VI	6.06	0 69	1 514	0 889
45	Renfrow	0.03	48	IV	5 88	0.74	1.393	1.727
46	Renfrow	0 03	49	IV	5 34	0.73	1.383	1.575
47	Renfrow	0.05	49	IV	5.34	0 73	1.383	1.575
48	Renfrow	0.05	50	IV	5 88	0.74	1.393	1.727
49	Shellaber	0.01	51	II	14.36	0.48	1 425	1.829
50	Shellaber	0.03	51	II	14 36	0 48	1 425	1.829



The Soil is Grant Silty Loam

Figure 5.1 Effect of Slope Steepness on Long Term Wheat Yields Under Selected Tillage Systems.

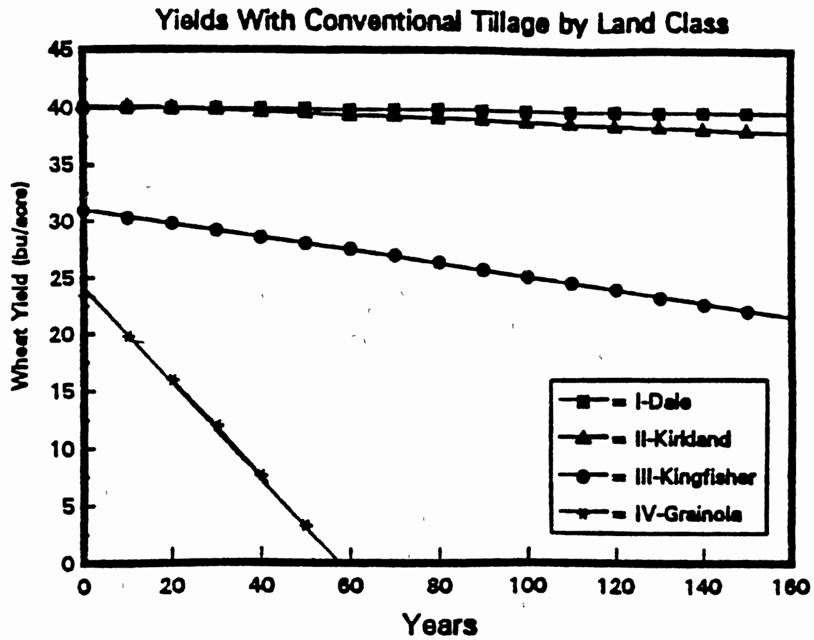
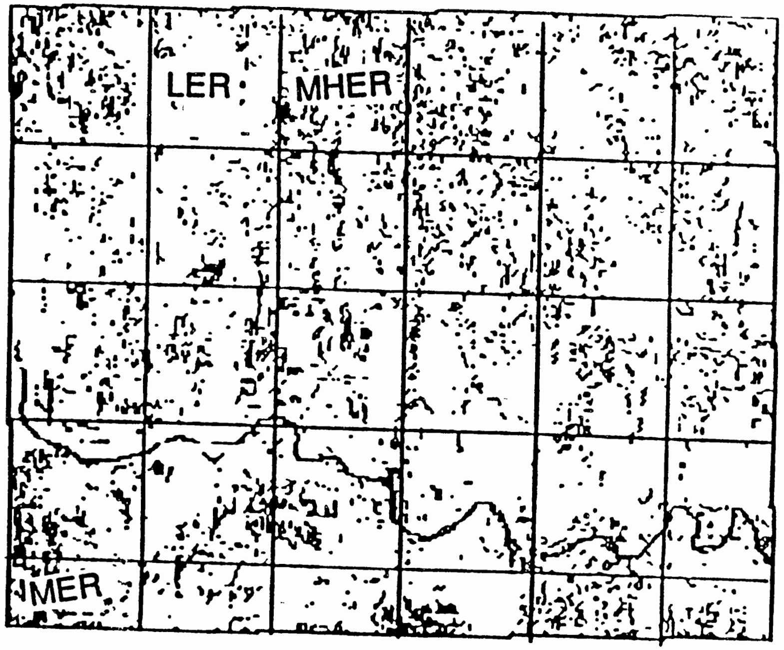


Figure 5.2 Projection of Wheat Yields Under Conventional Tillage on Selected Soils by Land Capability.

The Representative Farms

It is true that every farm in the county is unique with respect to its soil composition, fertility, erodibility, landscape and other soil characteristics that determine soil loss and erosion-productivity relationship. Nevertheless, it became necessary to construct only few representative farms to reduce the amount of data involved to a manageable size. Three representative farms were constructed from a digitized topographic data of the Grant county. In an earlier study Aw-Hassan and Stoecker (1992) used the digitized geographic data to subdivide the county into 30 six-by-six mile subareas or townships. Each block in panel b of figure 5.3 represents a township and each dot represents approximately a 10 acre (9.88 acres) soil unit which has the

5.3a Highly Erodible Land Used for Crop and Pasture Production



5.3b Highly Erodible Land Used for Crop Production

Figure 5.3. Location of Highly Erodible Land in Grant County Study Area.

potential of being considered as HEL. For this study ten townships were randomly selected from those 30 townships. Then the soil type composition was examined across the townships and the townships were divided into three categories based on the proportion of the HEL on each township. The first category were the townships which contained 33 percent of HEL or less. This lower limit (33 percent) was chosen because the SCS classifies a field as highly erodible if one-third (or 50 acres or more) of its acreage is HEL (USDA, 1990). The second category were the townships which contained 33 - 50 percent of HEL and the third category were the townships which contained above 50 percent of HEL. The objective of this exercise was to construct three 600 acre farms which contained different proportions of HEL, so that the effects of the proportion of HEL on the selection of tillage systems and farm income could be analyzed. One township was selected from each of the three categories and a 600 acre farm was constructed for each category from the selected township. The HEL acres on each farm were 33 percent or more of the total farm acres. The farms, therefore, were representative of only the highly erodible areas of the county. The highly erodible farms were focussed because there are potentially greater social benefits from soil conservation on HEL areas than on less erodible areas. The three farms will be referred to as Less Erodible (LER), Moderately Erodible (MER) and Mostly Highly Erodible (MHER). The LER farm is representative of the township located at the first row of the second column in figure 5.3b. The MER farm is representative of the township located at the fifth row of the first column in figure 5.3b. Finally, the MHER farm is representative of the township located at first row of the third column in figure 5.3b. The acreage of highly erodible land for the three farms are 158 acres for the LER farm, 255 acres for the MER farm and 410 acres for the MHER farm. The acreage of highly erodible land (HEL) of each soil type and the breakdown of the acreage of respective soil map units are given in Table 5.4. The three farms contained a total of 17 different soil types or map units. The number of soil map units included in farms LER, MER, and MHER were 8, 6, and 7, respectively. Major soils which constitute 80 percent or more of the township were included in each farm. It was assumed that the minor soils in the township were small in a single farm and would not change the results.

TABLE 5.4

SOIL MAP UNIT ACREAGES OF THE THREE REPRESENTATIVE FARMS

Map units	Map unit #	Acres of Soil LER Farm	MER Farm	MHER Farm
1	Bethany, SIL, 0-1%	99	--	--
2	Dale, SIL, 0-1%	--	86	--
3	Drummond, rarely flooded	48	--	--
4	Grainola, SICL, 1-3%	--	--	34
5	Grainola, SICL, 3-5%, HEL	--	--	86
6	Grant, SIL, 3-5%, HEL	--	110	--
7	Grant-Kingfisher, 4-8%, HEL	--	80	--
8	Kingfisher, SIL, 1-3%, HEL	39	--	--
9	Kingfisher, SIL, 3-5%, HEL	26	65	--
10	Kirkland, SIL, 0-1%	130	--	120
11	Kirkland, SIL, 1-3%, HEL	132	--	198
12	Mclain, rarely flooded	70	--	--
13	Pondcreek, 0-1%	56	135	--
14	Pondcreek, SIL, 1-3%	--	124	--
15	Port, SIL, occass. flooded	--	--	72
16	Renfrow, SICL, 2-5%, HEL	--	--	63
17	Tabler, SIL, 0-1%	--	--	27
	Total acres	600	600	600
	Total HEL Acres	197	255	410
	percent of HEL	33	43	68

CHAPTER VI

ANALYSIS AND RESULTS

A primary objective of this dissertation was to assess whether it was in the long term interest of wheat producers in North Central Oklahoma and Society to adopt reduced tillage systems in order to avoid soil productivity losses from soil erosion. The analysis consisted of two parts:

1) Analysis by individual soil types and
2) Farm level analysis.

Period of Analysis

The yield projections and economic analysis in this study cover a 150 year period. It might be argued that producers never plan longer than thirty to fifty years. However, producers do not expect to just abandon all property at the end of the planning horizon. Rather they expect to have a measure of wealth which can either be liquidated or passed to an heir. However the sale value of the land at the end of one producers planning horizon depends upon the value that a future producer(s) could derive from the property. Thus the current value of the land to the producer is derived from all future earnings.

Analysis by Individual Soil Types

In this analysis two approaches were used: Net Present Value analysis and Dynamic Programming analysis.

<u>Net Present Value Analysis</u>

The objective of this analysis was to determine the present value of alternative tillage systems for wheat by soil type and by land capability class for the study area. The enterprise budgets shown in Table 5.2 were used with the projected yields on each soil type to determine expected costs and returns (in current dollars) under each tillage system. A management fee equal to eight percent of one-third of the yield and property taxes were also deducted from the annual returns. It was assumed the specified tillage system was used throughout the planning period or until crop yields declined and reduced annual returns to the point where pasture was the best alternative. Average pasture rent was used as the proxy for returns from pasture land. The Net Present Value (NPV) of returns to land over the 150 year planning period are presented in Table 6.1. These are the returns from an acre of wheat the producer could expect if the entire 600 acre wheat base consisted of that soil type. The returns to land were defined as total revenue (which varied with remaining soil depth) less the sum of variable cost, machinery ownership cost, management fee and property taxes. The benefits and costs were valued in terms of 1990 prices and costs. The market price of wheat was assumed to be $3.00 per bushel, for producers who did not participate in the commodity program. It was assumed that producers who participated in the commodity program received $4.00 per bushel on 80 percent of their yield and 3 00 for 15 percent of their yield. The cases where the plow tillage system would not meet CC requirements are noted in Table 6.1. If the returns from wheat production fell below the returns from pasture ($8.40 per acre per year) per acre, it was assumed the land would be returned to grass.

TABLE 6.1

NET PRESENT VALUE[a] OF RETURNS TO LAND BY SELECTED SOIL TYPE UNDER ALTERNATIVE TILLAGE SYSTEMS AND BY PARTICIPATION AND NON-PARTICIPATION IN THE COMMODITY PROGRAM

Soil Type or Map Unit	Map No	Land Class	HEL	Crop Land	Wheat Yield	Without CC D Ch	With FACTA and CC				Average Soil Erosion			
							Plow	D Ch	Swp2	Swp1	Plow	D Ch	Swp2	Swp1
				acres	Bus		NPV (dollars/acre)				Tons/acre/year			
Bethany	4	I	-	27319	39	446	729	779	688	582	4.1	2.9	1.3	0.7
Dale	6	I	-	17574	45	670	998	1048	956	850	4.1	2 9	1 3	0 7
Hawly	23	I	-	11881	35	296	550	600	509	405	3.8	2 7	1 3	0 8
McClain	34	I	-	25471	42	559	863	913	822	716	3 0	2.6	1 1	0 6
Pond Creek	39	I	-	23652	41	517	811	863	775	670	4 3	3.2	1.5	0 8
Reinach	47	I	-	10487	45	672	998	1047	946	850	3 3	2 2	0 9	0 4
Attica	2	II	-	9854	30	104	324	369	295	208	5 0	3 4	1.6	0 8
Carwile-Attica	5	II	-	3380	29	190	329	376	296	230	5.5	3.7	1.8	0 9
Grant	17	II	-	9281	37	364	628	681	595	490	5.9	4.2	1.9	1.0
Kingfisher	24	II	-	62437	34	248	490	543	458	363	4.6	3 6	1.9	1.0
Kirkland	29	II	-	52929	35	289	539	592	505	403	3.7	2.8	1 3	0 8
Pond Creek	40	II	-	20312	38	398	668	722	637	534	10.2	7.7	3.7	2 0
Port	41	II	-	7571	44	625	936	992	907	803	3.8	2.3	1.0	0 6
Shellaberger	51	II	-	6098	35	284	530	386	502	402	4.9	3.5	1.7	0 8
Tabler	52	II	-	37539	36	334	595	644	554	448	4 4	2.8	1.2	0 7
Yahola	55	II	-	2431	35	296	550	600	509	405	4.1	3 0	1.6	0 8
Attica	3	III	WW	1562	26	-	*	208	137	96	9.3	6.6	3.2	1.8
Dale	7	III	Wa	2214	38	404	*	728	640	536	21.1	15.8	7.4	4.0
Grainola	15	III	WW	328	24	-	-	130	-	-	5.8	4 6	2.6	1.4
Grant	18	III	Wa	2303	34	245	*	538	457	362	12.0	8.7	4 0	2 2
Grant, eroded	19	III	Wa	3627	32	170	*	449	370	284	12.0	8.7	4.0	2 2
Kingfisher	25	III	Wa	722	30	102	*	353	287	203	10.6	8.2	4.3	2.3
Kingfisher, eroded	26	III	Wa	2847	27	-	*	220	161	96	20.7	16.1	8 3	4.5
Kingfisher-Wakita	27	III	Wa	3825	24	-	*	317	253	174	13.3	10.4	5 4	2 9
Kirkland	30	III	Wa	82077	32	169	*	448	369	284	8 8	6.6	3 2	1.6
Kirkland-Pawhusk	31	III	-	11386	29	154	328	370	309	242	7.8	6.8	2 8	1.4
Lela	32	III	-	2412	34	259	505	555	464	368	3.8	2.6	1.2	0.5
McClain-Drummond	35	III	-	17801	34	376	557	586	532	468	3.4	2.3	1.0	0.5
Norge	36	III	Wa	1651	34	247	*	541	458	363	9.9	7.4	3.5	1.9
Norge, eroded	37	III	Wa	1067	30	102	*	354	288	204	19.6	14.7	7.0	3.8
Gracemont	14	IV	-	1147	26	-	177	218	142	-	3.9	2.7	1.3	0 7
Grant-Kingfisher SIL	20	IV	Wa	761	28	-	*	271	218	164	24.9	18.9	9 3	5.1
Grant-Kingfisher ero	21	IV	Wa	2896	25	-	*	160	118	96	30.1	22.8	11 2	6 1
Kingfisher-Wakita	28	IV	Wa	1819	23	-	*	183	142	96	16.8	13.0	6.8	3.7
Renfrow	48	IV	Wa	4418	28	-	*	290	217	129	8.6	6.4	3 2	1.7
Renfrow, eroded	49	IV	Wa	14707	24	-	-	128	-	-	14.3	11.0	5 3	2 7
Gaddy	9	V	Wd	316	25	-	*	202	126	-	8.9	6.7	4 2	2 2
Oscar-Grant	38	V	WW	1927	25	-	*	193	124	96	32.2	22 8	11.8	7.3
Port&Pocasset	42	V	-	2995	33	437	634	670	615	549	3.8	2.4	1.1	0.6
Grant-Port	22	VI	Wa	2560	28	-	*	261	205	132	30.1	19.8	9.3	5.9
Madsham-Port	33	VI	WW	2036	24	129	*	180	169	152	24 9	19.2	10 3	5.9

[a] Net Present Value of Future Earnings Capitalized at 8.25 percent. Only soils where returns from wheat production were greater than returns from pasture are shown.

Abbreviations used

HEL = Highly Erodible Land, Wa = HEL by water, Wd = HEL by wind, WW = HEL by Wind or Water.

Tillage Systems, D. Ch. = Disk Chisel, Swp2 = Sweep twice, Swp1 = Sweep once.

- indicates that pasture returns are greater than that from wheat.

* indicates that plow could not meet the Conservation Compliance.

Choice of the Discount Rate. An iterative method was used to find the discount rate which most closely equated expected future earnings to the actual sale price of individual tracts of farmland sold in Grant county in 1991. First each parcel of farmland sold in 1991 was located on the county soils map. The predicted sale value for the parcel was determined by multiplying the number of acres in each map unit by the capitalized earnings from that soil type. A trial discount rate was used to capitalize returns from the disk-chisel system for each soil type or map unit. The estimated sales price for each tract was subtracted from the actual sales price. The deviations were squared and summed over all farm land parcels sold in 1991. The discount rate was changed and the process was repeated. The discount rate of 8.25% which gave the minimum sum of squared deviations between the actual and predicted sale prices was selected for the study.

The net present value of returns discounted at 8.25 percent are shown in Table 6.1. The NPV of the Disk Chisel system was higher than for the other systems on all soils regardless of whether or not the producer participated in the commodity program. Table 6.1 indicates that in the absence of conservation compliance restrictions, a larger proportion of the HEL area would be planted to wheat in the presence of the commodity program than would be the case at the expected market price of $3.00 per bushel.

The capitalized thirty year earnings and discounted sale or remaining values earnings are summarized by land capability class and tillage system in Figure 6.1. In Figure 6.1 the total NPV over the 150 year planning period was arbitrarily divided into two parts. The first part consisted of the capitalized returns from the first 30 years. The "sale value" represents the discounted returns over the remaining 120 years. As shown in Figure 6.1 a discount rate of

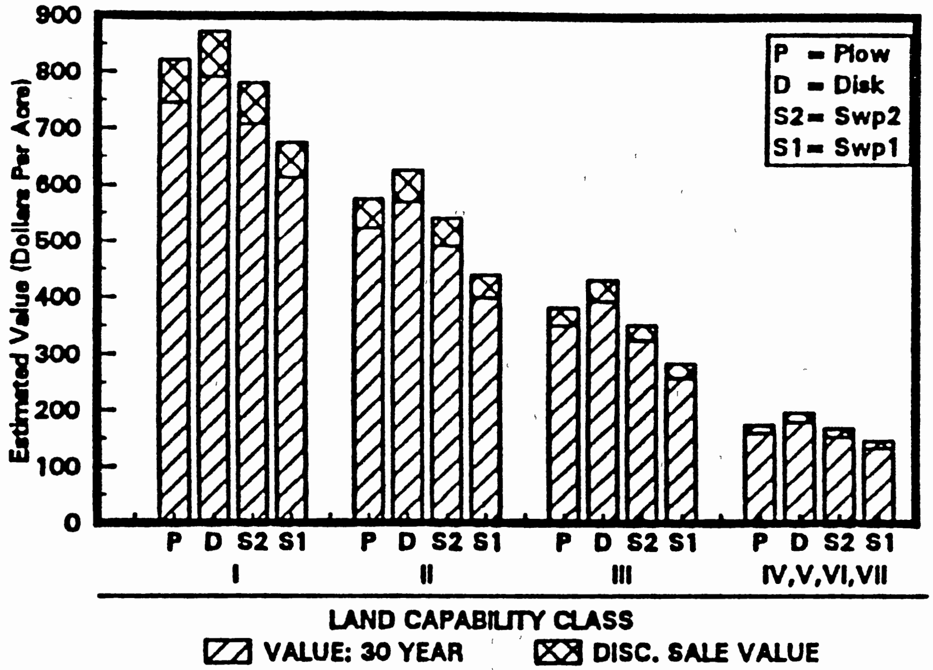


Figure 6.1. Effect of Tillage System Choice on Long Term Returns by Land Capability Class under the Food Agriculture, Conservation and Trade Act of 1990.

8.25 percent means that most of the value from the land holding is derived from the first 30 years.

Dynamic Programming Analysis

The net present value calculations shown above in Table 6.1 indicated that the disk chisel system was the most profitable on all soils when tillage was more profitable than pasture. However, it is difficult to determine with only a NPV comparison whether or not it is profitable for a producer to change from one tillage system to another within the planing horizon. Switching from one tillage system to another would be more likely in highly erodible soils at lower discount rates when a longer planning horizon has been assumed. Four HEL soils were selected from Land Capability Classes II, III, IV and VI. The selected soils from the four classes, were respectively, Shellabarger fine sandy loam with a 3 percent slope, Kingfisher silty loam with a 5 percent slope, Grant silty loam with a 5 percent slope, and a Port silt clay loam with a 7 percent slope. These soils were extensively used for crop production according to the 1984 NRI survey for Grant county (see Table 4.1). These soils had the highest potential loss of returns due to soil erosion.

A discrete dynamic programming model was formulated to determine the most profitable sequence of tillage systems over the planning horizon. The model used is presented as:

$$\text{MAX NPV} = \sum_{t=0}^{T-1} \sum_{i=1}^{I} P\, Y_{i,t}\, (X_t) \cdot (1+r)^{-t} + R\,(X_T)\,(1+r)^{-T}$$

$$X_0 = \bar{X}_0 \,,\; X_t = X_{t-1} - E_{i,t-1}$$

where $Y_{i,t}$ is the yield if system i used in year t

X_t is the depth of uneroded soil at time t

$E_{i,t}$ is the erosion rate of the ith tillage system used in year t

$R(X_T)$ is the sale value of the land which depends on the uneroded depth at time T

r is the discount rate

The first term of the equation gives the NPV of a stream of income from an optimal sequence of tillage systems while the last term ($R(X_T)$ / (1+r) ^ T)) gives the present value of a final sale value.

The erodible soil depth was divided into 200 states. The planning horizon was divided into nine 10-year decision periods. It was assumed that the approximate life of most agricultural machinery was 10 years. A final stage of 60 years was included in the analysis to estimate the final sale value $R(X_T)$. At the beginning of each period the farmer chooses the tillage system that gives maximum present values of current plus present value of future returns.

The decision variable in this DP model is the tillage system (or pasture) for each decision period. In other studies researchers have used a percentage of the acreage devoted to wheat (Burt, 1981) or a percentage of the land in a particular rotation (Segarra, 1986) as decision variables.

The DP model was solved separately for all four soils for wheat prices of $3 and $4 per bushel. Discount rates of (0,1,2 and 4) percent were used to test the sensitivity of cropping system choice to the discount rate.

The results of the DP model for the four soils are given in Table 6.2. The DP results indicate the optimal sequence of tillage systems is soil specific and is sensitive to discount rates less than four percent. The optimal sequence is also sensitive to the price of wheat.

When the price of wheat was $3 per bushel, the optimal sequence of tillage systems given by the DP for the Shellabarger, Kingfisher and Grant soils were the same as obtained from the simple NPV analysis. The DC system gave the highest NPV for Shellabarger soil while pasture was the most profitable choice for the Kingfisher and Grant soils. However, for the Port soil a DC and pasture sequence was optimal. The discount rate had no effect on the above results when price of wheat was $3 per bushel.

When the price of wheat was $4 per bushel farmers, it is shown in Table 6.2 that with a zero discount rate the optimal tillage sequence consisted of a combination of sweeps followed by disk chisel system on all four soils. When a discount rate of one percent was assumed the disk chisel system became the optimal system for Shellabarger, Kingfisher, and Grant soils.

TABLE 6.2

THE OPTIMAL SEQUENCE OF WHEAT TILLAGE SYSTEMS FOR FOUR GRANT COUNTY CLASS II, III, IV AND VI SOILS UNDER ALTERNATIVE WHEAT PRICES AND DISCOUNT RATES.

Soils	10	20	30	40	50	60	70	80	90	150	NPV	eroded soil depth
		(Wheat price $3 per bushel)			Tillage System						dollars per acre	cm
0% discount rate												
Shellaberger II	DC	DC	DC	DC	DC	DC	DC	DC	DC	DC	2334	10.9
Kingfisher III	pasture	pasture	pasture	pasture	pasture	pasture	pasture	pasture	pasture	pasture	1260	1 2
Grant IV	pasture	pasture	pasture	pasture	pasture	pasture	pasture	pasture	pasture	pasture	1260	1 2
Port VI	DC	DC	DC	DC	pasture	pasture	pasture	pasture	pasture	pasture	1597	14 4
There was no change in the above optimal systems as a result of higher discount rates.												
			(Wheat price $4 per bushel)									
0% discount rate												
Shellaberger II	SWP2	SWP2	SWP2	SWP2	DC	DC	DC	DC	DC	DC	7135	9 4
Kingfisher III	SWP2	SWP2	SWP2	SWP2	SWP2	SWP2	DC	DC	DC	DC	3697	16 0
Grant IV	SWP2	SWP2	SWP2	SWP2	SWP2	SWP2	DC	DC	DC	DC	3942	21 7
Port VI	SWP1	SWP1	SWP1	SWP1	SWP1	SWP2	SWP2	SWP2	SWP2	DC	5125	30 4
1% discount rate												
Shellaberger II	DC	DC	DC	DC	DC	DC	DC	DC	DC	DC	3856	10 9
Kingfisher III	DC	DC	DC	DC	DC	DC	DC	DC	DC	DC	2096	19 7
Grant IV	DC	DC	DC	DC	DC	DC	DC	DC	DC	DC	2194	27 6
Port VI	SWP2	SWP2	SWP2	SWP2	SWP2	SWP2	SWP2	SWP2	SWP2	DC	2906	33 8
2% discount rate												
Shellaberger II	DC	DC	DC	DC	DC	DC	DC	DC	DC	DC	2455	10 9
Kingfisher III	DC	DC	DC	DC	DC	DC	DC	DC	DC	DC	1410	19 7
Grant IV	DC	DC	DC	DC	DC	DC	DC	DC	DC	DC	1454	27 6
Port VI*	DC	DC	DC	DC	DC	DC	DC	DC	DC	pasture	1156	30 4

abreviations used

D= disk chisel, SWP1= sweep once, SWP2= sweep twice

* For port (VI) soil DC-pasture sequence became the most profitable at 4% discount rate

However, for the Port soil the sweep twice system followed by the disk chisel sequence was optimal. When the discount rate was one percent and the price of wheat was $4 the disk chisel was always the most profitable for the Kingfisher and Grant soils. However, pasture was the optimal choice for these soils when the wheat price was $3 per bushel. The expected eroded soil depths for those two soils were 1.2 and 1.6 cm under $3 wheat price and 16.0 and 21.7 cm, respectively, under 4 dollar wheat price. The results with Kingfisher and Grant soils demonstrate that higher agricultural price supports without adequate erosion controls could encourage more soil depletion by making crop production more profitable on marginal soils.

When a discount rate of 2 percent or more was assumed the DC system was the optimal choice under either wheat price as long as the annual returns from wheat production exceeded those from pasture. The empirical results provided a sequence of choices that maximized the present value of net returns and the present value of the farm value. Private optimal paths of soil erosion rates for each farm depended on the discount rates, yield increment, prices, and erosion restrictions.

Farm Level Analysis

Objectives

The above analysis by individual soil type assumed that the whole 600 acre wheat base consisted of one soil type. However, the mixture of soils is important because a producer with more acres of HEL has more economic incentive to select a tillage system which maintains soil productivity than a producer whose farm contains fewer acres of HEL. To determine the effect of mixture of soils has on the relative profitability of alternative tillage systems for wheat, the three representative farms, discussed in chapter 5, were analyzed using the discrete-dynamic model developed in chapter 4.

The objectives of the farm level analysis were:

a) To determine the optimal tillage sequence, farm income and erosion rates for the three representative farms under different assumptions on wheat prices, discount rates and technological improvements.

b) To determine the effects of the soil erosion limits on the choice of wheat tillage systems, farm income and erosion rates.

c) To determine the effect of erosion charges on the choice of wheat tillage systems, farm income and erosion rates.

d) To determine the relative cost effectiveness of erosion charges and uniform erosion control standards.

Model Assumptions

The objective function of the farm level dynamic economic model, discussed in chapter 4, was to maximize the sum of the net present value of the returns of all soil types in the farm over the planning horizon. The objective could be achieved by choosing an optimal sequence of wheat tillage systems and/or pasture in each investment or decision period. A decision or investment period was assumed to be 10 years. It was assumed the farm operator would purchase and replace all the machinery at the beginning of each discrete 10-year time period. This assumption implies that the farmer's adoption of tillage systems is a discrete choice contingent on an average machinery life of 10 years. The first constraint is that each soil type should be either tilled or returned to pasture. It was expected that only one tillage system would be used for the whole farm and that marginal soils would be returned to pasture when wheat production became less profitable than use of the land as pasture. This is because each tillage system has fixed machinery investment costs which must be paid when a given system is used. Thus it is not economical to use one tillage system for one group of soils and another tillage system for other soils. However, to allow more flexibility in the selection of wheat tillage systems a mixed tillage system was defined. The mixed tillage system consisted of the same equipment required for the disk-chisel tillage system plus sweep tillage equipment. The mixed tillage system allowed the farm operator to use the disk-chisel for less highly erodible soils and the sweep equipment for the most highly erodible soils if that was more profitable than using a single tillage system with lower fixed investment cost. The second constraint was that the total acreage of the soil types used for tillage and pasture should not exceed the farm size of 600 acres.

The third constraint of the model was that the remaining soil depth at the beginning of each time period is equal to the soil depth of the last period minus the eroded soil depth which occurred in the last period. The amount of erosion depends on the tillage system which was used. This constraint must hold for all soil types on the farm and for all time periods. Production costs were assumed to be the same for all soil types. In reality this may not be the case because when a soil is highly eroded, increased levels of fertilizer inputs may be required to compensate lost nutrients and fuel and repair costs may increase due to changes in soil structure. However, no data were available to estimate those costs.

Scenarios for the Analysis

Each representative farm model was solved using different wheat price levels, discount rates, rates of technological improvement and soil conservation policy variables. The representative farms were described in chapter 5 The analysis also assumes that price is exogenously determined and each price level remains constant during the planning horizon. The price levels for wheat were assumed to be $3 per bushel, which was the average market price from 1986 to 1990, and a target price of $4 per bushel. In the case of the target price, 15 percent of the total wheat base known as flex acres are not eligible to receive the target price. Farmers participating in the commodity program were, therefore, assumed to receive $4 per bushel for 85 percent and $3 per bushel for 15 percent of their yields. The setaside of base acres was not considered because it is not required to participate in the 1993 program (Sanders, Anderson, and Sahs, 1992). The two price levels provided a contrast between the optimal wheat tillage systems when farmers produced outside the commodity program at the market price and the optimal wheat tillage systems when farmers met conditions to participate in the commodity program and received the target price. Higher prices may encourage farmers to cultivate marginal soils if no restrictions, such as requiring conservation plans on HEL, are imposed. The returns from pasture were assumed to be constant at $8.40 per acre.

The three discount rates used in the analysis were zero percent, 4 percent and 8 percent. The zero discount rate represents the situation where the present value of the future erosion damages are weighted the same as the present value of the current erosion damages. In other words, there is no time preference of the occurrence of the benefits and costs. In general the society has a lower discount rate than the private decision-maker (Dasgupta and Pearce, 1972). Therefore, assuming that there are no off-site damages, the zero discount rate scenario would be a lower bound on society's desire for the adoption of conservation tillage systems to maintain future production.

The levels of technological growth were assumed to be zero percent, 0.7 percent and 1.4 percent. The 0.7 percent technological growth is the rate of the yield increment of Oklahoma wheat for the last three decades (1960 - 1990) (Oklahoma Agricultural Statistics). This is an increase of about 2 bushels of wheat per acre per decade. Young et al. (1985) analyzed the combined effect of technological growth and soil erosion on productivity. When technology is assumed to be constant, the projected yield loss will be less than when technological growth is assumed. From the private decision-makers' point of view, everything else remaining constant, the higher the technological improvement the greater is the yield loss or damage from erosion and, hence, the greater the incentive to adopt the conservation tillage. Higher discount rates, however, may offset that incentive. From the society's point of view future yield losses or damages increase as the discount rate declines and technological growth increases. That is low discount rates and increased technological growth increase the social desirability for adopting conservation tillage.

Two types of policy variables used in this study to affect erosion control were limits on annual soil erosion and taxes on erosion. Three levels of erosion limits were identified. The first erosion limit was defined in terms of farm tillage plans approved by the Soil Conservation Service (SCS) as currently required by the Conservation Compliance Provision of the 1990 Farm Program. Under the current SCS guidelines only the plow system will not meet the Conservation

Compliance guidelines for water erosion on highly erodible land in the study area when wheat is growing (Vaughn, 1992). All the tillage systems will meet the guidelines for wind erosion on highly erodible land when planted to wheat. The other two soil erosion restrictions evaluated were restricting annual erosion to twice the soil loss tolerance (2T) and restricting annual erosion to the tolerance (1T) level. The purpose of the erosion changes was to internalize the external cost of soil erosion so that farm operators would bear these costs and as a result choose a socially optimal level of erosion control. Ribaudo and associates (1990) estimated that the value of annual average productivity loss of soil erosion was 42 cents per ton of soil erosion for the United States and 24 cents for the Southern Plains region. They estimated that the off-site damage was $1.78 per ton of soil erosion for the United States and $2.02 for the Southern Plains. There were no estimates available for Oklahoma or for the study area. Thus it was assumed that $2.25 per ton of soil erosion which is higher than that estimated for the Southern plains, was the maximum external damage for the study area. Three levels of erosion charges were selected and included in the farm models. These charges were $0.75, $1.50, and $2.25 per ton of eroded soil. The private discrete decision models described earlier were modified by subtracting the tax payments due to soil loss from the returns in the objective function. The three representative farm models were then solved subject to the erosion charge.

A total of 45 scenarios were analyzed. Under the market price level there were 3 discount rates and 3 technological growth rates. Under the target price there were 3 levels of soil erosion limits and 3 levels of erosion charges. So, there were 15 experiments for each representative farm.

The programming models for the three representative farms were set up by using GAMS (General Algebraic Modeling systems) procedure (Brooke, et al. 1988). There were 15 decision periods and 5 systems. So, in total there were 600, 450, and 525 decisions to make for the LER, MER, and MHER farms, respectively. The decisions were which tillage system to use and whether to produce wheat or pasture on each soil type within the farm. The models were solved by GAMS. The non-linear solver used in GAMS is MINOS (Modular In-core Non-linear system) Murtagh and Saunders (1983). Each solution required about .65 megabytes of hard drive memory and it took less than 30 seconds on a 486/25E personal computer. The GAMS program used for the LER farm is given in appendix B. The programs for the other farms are the same but with different specific soil data which are given in Tables 5.3 and 5.4.

Optimal Tillage Sequence, Erosion Rates
and Farm Income with Market Price

Base Scenario. The initial scenario assumed that operators received the market price, had a zero discount rate and expected no technological progress. In that situation the value per ton of soil was constant. As shown in Table 6.1, DC was found to be the optimal tillage system for the less erodible and moderately erodible farms. While on the mostly highly erodible farm, the operator received the highest returns by converting the land into pasture. The per acre values (with zero discount rates) were $2008 for the LER farm, $2515 for the MER farm, and $1500 for the MHER farm.

The soil loss by a continuous DC tillage system, assuming no technological advance, could eventually erode some soils up to a point where wheat is no longer a profitable venture. The MER farm was representative of such a situation where after 20 and 30 years of continuous DC 80 and 145 acres were, respectively, taken out of wheat production because the remaining soil depth could not support an economic yield.

Those results suggest that even if the farmer was concerned about future generations, the DC tillage system with higher erosion rates than the sweep tillage systems would be chosen because it was more profitable than the less erosive sweep tillage system. Moreover the above solutions, although they are privately optimal, they obviously do not ensure a long-term crop productivity of some HEL soils.

Effect of Technology. Introduction of technological progress into the base scenario had a dual effect. First it increased the value of soil over time which increased the user cost of soil erosion and provided farmers greater incentive to conserve soil. Secondly, it increased the yields on marginal soils which made cultivation more profitable. Without technological progress those marginal soils were more profitable under pasture. The optimal tillage systems, wheat acreage and pasture acreage when a 0.7 percent annual yield increment was assumed, are reported in columns 5, 6, and 7 of Table 6.3. Columns 8, 9, and 10 of Table 6.3 contain the results when a 1.4 percent annual yield increment was assumed.

When the annual yield growth was assumed to be 0.7 percent the DC tillage system was chosen on all the three farms. The wheat acreage on the LER and on the MER farms decreased in the short-term (10-20 years) and then increased as the end of the planning horizon approached. Consequently, the total soil loss was lower with the yield increment than without it. However, wheat production became profitable on the MHER farm due to the yield increment. So, in this case, wheat acreage increased and the soil erosion rates were greater with the yield increment than without it.

TABLE 6.3

OPTIMAL TILLAGE SYSTEMS, WHEAT ACREAGE, PASTURE ACREAGE AND NET PRESENT VALUE OF PROFITS UNDER MARKET PRICE AND 0% DISCOUNT RATE FOR THREE REPRESENTATIVE GRANT COUNTY FARMS

1	2	3	4	5	6	7	8	9	10
	Yield growth = 0%			Yield growth = 0.7%			Yield growth = 1.4%		
				LER Farm					
	NPV $/acre	2008		NPV $/acre	13786		NPV $/acre	40180	
Years	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture
1-10	Disk chisel	552	48	Disk chisel	526	74	SWEP2	526	74
11-20	Disk chisel	552	48	Disk chisel	526	74	SWEP2	526	74
21-30	Disk chisel	552	48	Disk chisel	552	48	SWEP2	552	48
31-40	Disk chisel	552	48	Disk chisel	552	48	SWEP2	552	48
41-50	Disk chisel	552	48	Disk chisel	552	48	Disk chisel	600	0
				MER Farm					
	NPV $/acre	2515		NPV $/acre	14694		NPV $/acre	42721	
Years	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture
1-10	Disk chisel	600	0	Disk chisel	455	145	SWEP2	455	145
11-20	Disk chisel	600	0	Disk chisel	455	145	SWEP2	455	145
21-30	Disk chisel	520	80	Disk chisel	455	145	SWEP2	455	145
31-40	Disk chisel	455	145	Disk chisel	455	145	SWEP2	600	0
41-50	Disk chisel	455	145	Disk chisel	455	145	SWEP2	600	0
				MHER Farm					
	NPV $/acre	1500		NPV $/acre	11539		NPV $/acre	36022	
Years	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture
1-10	None	0	600	Disk chisel	417	183	SWEP2	417	183
11-20	None	0	600	Disk chisel	417	183	SWEP2	480	120
21-30	None	0	600	Disk chisel	480	120	SWEP2	514	86
31-40	None	0	600	Disk chisel	514	86	SWEP2	600	0
41-50	None	0	600	Disk chisel	514	86	SWEP2	600	0

When the annual yield increment was assumed to be 1.4 percent the sweep tillage system was the most profitable choice on all the three farms. The net effect of technological progress was a reduction in erosion rates on the LER and MER farms, because the sweep tillage system was included in the optimal solution. But on the MHER farm the net effect was an increased erosion rate compared to the base scenario because more land was cultivated and sweep tillage has a higher erosion rate than pasture.

From the above analysis we conclude that even if farmers were concerned about future generations (that is assuming a zero discount rate) erosion rates could be increased over time by cultivating more marginal soils due to technological improvement. Optimal soil erosion paths at zero discount rate and the three levels of yield growth are graphically depicted in Figure 6.2. The graphs show that the greater the yield increment was the greater the incentive to conserve soil which was already in cultivation and, thus, the lower the erosion rate. However, because it increased the conversion of marginal soils from pasture to cultivation the overall erosion rates were higher with the technological progress than without it.

Effect of the Discount Rate. Now let us change the base scenario by increasing the discount rate to 4 percent. The results are reported in Table 6.4. No change in optimal choices was found when technology was assumed constant for all the three farms. The disk chisel system was selected when cultivation was profitable (LER and MER farms) and pasture was used for marginal soils (MHER farm). The soil erosion rate declined on the MER farm as more marginal land was taken out of wheat production and returned to pasture. The per acre farm values were 311, 395, and 208 dollars for LER, MER, and MHER farms, respectively.

When the discount rate was assumed to be 4 percent, and a positive yield growth was assumed, the DC tillage system remained the most profitable choice on all the three farms. The per acre farm values are given in Table 6.4.

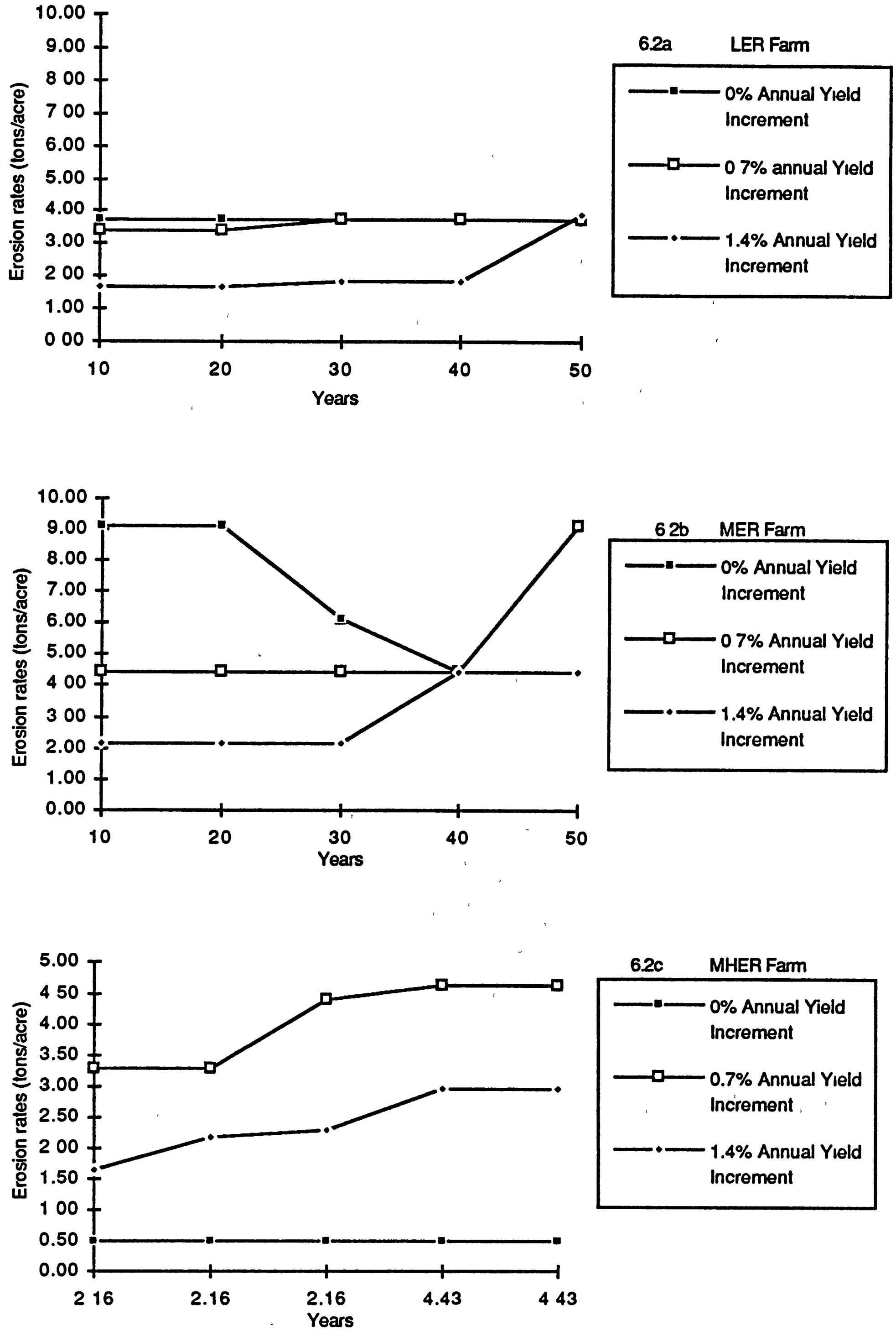


Figure 6.2. Effect of Technological Progress on Optimal Paths of Erosion Rates at Market Price and 0% Discount Rate.

TABLE 6.4

OPTIMAL TILLAGE SYSTEMS, WHEAT ACREAGE, PASTURE ACREAGE AND NET PRESENT VALUE OF PROFITS UNDER MARKET PRICE AND 4% DISCOUNT RATE FOR THREE REPRESENTATIVE GRANT COUNTY FARMS

1	2	3	4	5	6	7	8	9	10
	Yield growth = 0%			Yield growth = 0.7%			Yield growth = 1.4%		
				LER Farm					
	NPV $/acre 311			NPV $/acre 820			NPV $/acre 1589		
Years	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture
1-10	Disk chisel	552	48	Disk chisel	552	48	Disk chisel	552	48
11-20	Disk chisel	552	48	Disk chisel	552	48	Disk chisel	552	48
21-30	Disk chisel	552	48	Disk chisel	552	48	Disk chisel	552	48
31-40	Disk chisel	552	48	Disk chisel	552	48	Disk chisel	552	48
41-50	Disk chisel	552	48	Disk chisel	552	48	Disk chisel	600	0
				MER Farm					
	NPV $/acre 395			NPV $/acre 936			NPV $/acre 1755		
Years	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture
1-10	Disk chisel	600	0	Disk chisel	600	0	Disk chisel	600	0
11-20	Disk chisel	600	0	Disk chisel	600	0	Disk chisel	600	0
21-30	Disk chisel	520	80	Disk chisel	600	0	Disk chisel	600	0
31-40	Disk chisel	455	145	Disk chisel	600	0	Disk chisel	600	0
41-50	Disk chisel	455	145	Disk chisel	600	0	Disk chisel	600	0
				MHER Farm					
	NPV $/acre 208			NPV $/acre 613			NPV $/acre 1333		
Years	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture
1-10	None	0	600	Disk chisel	480	120	Disk chisel	514	86
11-20	None	0	600	Disk chisel	600	0	Disk chisel	600	0
21-30	None	0	600	Disk chisel	600	0	Disk chisel	600	0
31-40	None	0	600	Disk chisel	600	0	Disk chisel	600	0
41-50	None	0	600	Disk chisel	600	0	Disk chisel	600	0

When the discount rate was assumed to be 4 percent the net effect of technological progress was an increase in erosion rate on all the three farms because more marginal soils were cultivated and the incentive for conservation due to future yield growth was reduced by the increased discount rate. The acreage of pasture in the MER farm and the MHER farm was zero when the annual yield increment was assumed to be 0.7 percent. However, in the LER farm the acreage of pasture declined to zero after 40 years when a 1.4% of annual yield growth was assumed. Figure 6.3 depicts the optimal paths of annual erosion rates with and without technological change. The figure shows that the erosion rate, when a 4 percent discount rate was assumed, was always greater when expected yield growth was positive than when expected yield growth was zero. The effect of the technological growth on the optimal tillage system and, hence, on the erosion rate was greater in the MHER and MER farms than on the LER farm.

As shown in Table 6.5 the 8 percent discount rate affected the farm value but did not change the tillage systems or erosion rates in any significant way. The estimated present value of the farm increased with the assumed yield increment.

The above results conclude that wheat producers farming HEL in Grant county who produce outside the commodity program would find the disk chisel the most profitable system. Producers farming marginal soils where wheat was not profitable at that market price would find pasture as a better option. Producers will find sweep systems profitable only if their discount rate is zero and they have positive expectations about future yield growth. However, optimal private solution even when discount rate is zero may not protect the long-term productivity of some HEL soils. Technological improvement and

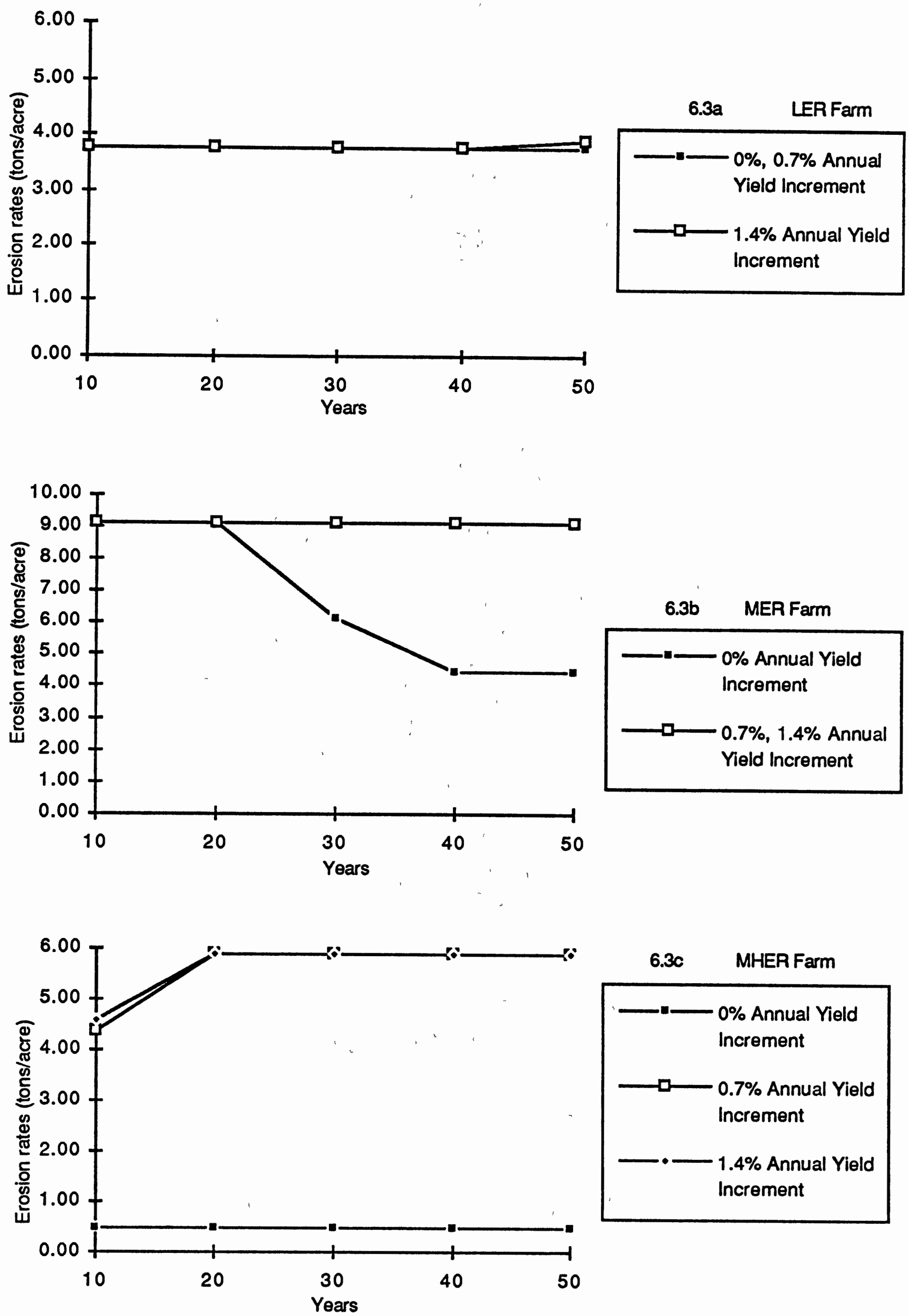


Figure 6.3. Effect of Technological Progress on Optimal Paths of Erosion Rates at Market Price and 4% Discount Rate.

TABLE 6.5

OPTIMAL TILLAGE SYSTEMS, WHEAT ACREAGE, PASTURE ACREAGE AND NET PRESENT VALUE OF PROFITS UNDER MARKET PRICE AND 8 PERCENT DISCOUNT RATE FOR THREE REPRESENTATIVE GRANT COUNTY FARMS

1	2	3	4	5	6	7	8	9	10
	Yield growth = 0%			Yield growth = 0.7%			Yield growth = 1.4%		
				LER Farm					
	NPV $/acre 133			NPV $/acre 252			NPV $/acre 400		
Years	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture
1-10	Disk chisel	552	48	Disk chisel	552	48	Disk chisel	552	48
11-20	Disk chisel	552	48	Disk chisel	552	48	Disk chisel	552	48
21-30	Disk chisel	552	48	Disk chisel	552	48	Disk chisel	552	48
31-40	Disk chisel	552	48	Disk chisel	552	48	Disk chisel	552	48
41-50	Disk chisel	552	48	Disk chisel	552	48	Disk chisel	600	0
				MER Farm					
	NPV $/acre 168			NPV $/acre 300			NPV $/acre 462		
Years	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture
1-10	Disk chisel	600	0	Disk chisel	600	0	Disk chisel	600	0
11-20	Disk chisel	600	0	Disk chisel	600	0	Disk chisel	600	0
21-30	Disk chisel	520	80	Disk chisel	600	0	Disk chisel	600	0
31-40	Disk chisel	455	145	Disk chisel	600	0	Disk chisel	600	0
41-50	Disk chisel	455	145	Disk chisel	600	0	Disk chisel	600	0
				MHER Farm					
	NPV $/acre 86			NPV $/acre 174			NPV $/acre 315		
Years	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture
1-10	None	0	600	Disk chisel	514	86	Disk chisel	600	0
11-20	None	0	600	Disk chisel	600	0	Disk chisel	600	0
21-30	None	0	600	Disk chisel	600	0	Disk chisel	600	0
31-40	None	0	600	Disk chisel	600	0	Disk chisel	600	0
41-50	None	0	600	Disk chisel	600	0	Disk chisel	600	0

positive discount rates (for example 4% and 8%) further contributed to greater soil loss.

Optimal Tillage Sequence, Erosion Rates
and Farm Income with Target Price

Generally agricultural programs are developed to support farmer's income. Those programs, however, may have undesired effects on other national objectives like control of soil erosion. That is one reason for continuous modifications of agricultural programs. Additional provisions describing programs like Conservation Reserve Program (CRP), Conservation Compliance, the sodbuster, and others, are included in the farm legislation in order to accord those multiple objectives. The effect on soil loss and farm income of a target price for wheat (4 dollars per bushel adjusted for the 15 percent of flex acreage) and different erosion restrictions were examined. Hereinafter, we are assuming a constant technology and a discount rate of 8 percent.

Conservation Compliance Erosion Limits. The disk chisel system will meet the Soil Conservation Service erosion guide lines for the Conservation Compliance (CC) as they are currently implemented in the study area. Operators could still use the disk chisel system and be in compliance. The optimal tillage sequence and the acreage in wheat and the acreage in pasture, when farmers received a target price of $4/bushel and when the erosion rate on HEL was restricted by the SCS recommended guidelines to meet the conservation compliance, are reported in Table 6.6. There was no difference in the optimal tillage systems on the LER farm between the target price and the market price because the DC system meets the CC requirements for all

TABLE 6.6

OPTIMAL TILLAGE SYSTEMS, WHEAT ACREAGE, PASTURE ACREAGE AND NET PRESENT VALUE OF PROFITS UNDER TARGET PRICE AND 8 PERCENT DISCOUNT RATE FOR THREE REPRESENTATIVE GRANT COUNTY FARMS

1	2	3	4	5	6	7	8	9	10
Erosion limit to:									
	CC limit			2T level			1T level		
				LER Farm					
	NPV $/acre 368			NPV $/acre 368			NPV $/acre 337		
Years	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture
1-10	Disk chisel	552	48	Disk chisel	552	48	Disk+sweep	552	48
11-20	Disk chisel	552	48	Disk chisel	552	48	Disk+sweep	552	48
21-30	Disk chisel	552	48	Disk chisel	552	48	Disk+sweep	552	48
31-40	Disk chisel	552	48	Disk chisel	552	48	Disk+sweep	552	48
41-50	Disk chisel	552	48	Disk chisel	552	48	Disk+sweep	552	48
				MER Farm					
	NPV $/acre 429			NPV $/acre 372			NPV $/acre 281		
Years	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture
1-10	Disk chisel	600	0	Disk+sweep	520	80	Disk+sweep	345	255
11-20	Disk chisel	600	0	Disk+sweep	520	80	Disk+sweep	345	255
21-30	Disk chisel	600	0	Disk+sweep	520	80	Disk+sweep	345	255
31-40	Disk chisel	600	0	Disk+sweep	520	80	Disk+sweep	345	255
41-50	Disk chisel	600	0	Disk+sweep	520	80	Disk+sweep	345	255
				MHER Farm					
	NPV $/acre 286			NPV $/acre 269			NPV $/acre 220		
Years	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture
1-10	Disk chisel	600	0	Disk chisel	514	86	Disk+sweep	514	86
11-20	Disk chisel	600	0	Disk chisel	514	86	Disk+sweep	514	86
21-30	Disk chisel	600	0	Disk chisel	514	86	Disk+sweep	514	86
31-40	Disk chisel	600	0	Disk chisel	514	86	Disk+sweep	514	86
41-50	Disk chisel	600	0	Disk chisel	514	86	Disk+sweep	514	86

cultivated soils. The farm value increased from 133 to 368 dollars per acre. In the case of the MER farm cultivated area increased due to higher returns from wheat and, hence, total erosion over the fifty years planning period was greater. The farm value increased from 168 to 429 dollars per acre. The MHER farm shifted from complete pasture under the market price to complete DC tillage under the target price scenario. Farm value increased from 86 to 286 dollars per acre. Erosion rates were, of course, greater under the target price because the higher price made it profitable to farm the more marginal land for longer periods of time.

The conclusion from this section is that the present value of net farm returns was greater when the target price was assumed than when the market price was assumed. Thus, producers on all three farms would prefer to meet the conditions for CC and remain in the program than to produce outside the program. Erosion rates of more marginal soils were greater than the tolerance level under the target price even when the CC was satisfied. Thus, it could be concluded that one consequence of the program to support farm income in the current period is reduced future productivity on some soils.

Impact of Further Erosion Limits (2T and 1T). The disk chisel system meets the conservation compliance in all soils used in the study. Nevertheless, there are two reasons to consider further reductions on erosion rates. First, the disk chisel will generate erosion rates of more than 2 times the tolerance value on some HEL soils. For example, the Grant and Kingfisher soils have an average soil loss of 22.78 and 16.1 tons/acre/year, respectively, under the DC system. So the DC tillage system, although it meets the conservation compliance, has an erosion rate which is too high to protect long-term productivity of those soils. Secondly, it is likely that erosion rates determined by private decision makers who maximize private profits are not socially optimal due to the external damages that eroded soil causes to lakes, reservoirs and water ways, or due to the divergence of private and social discount rates.

The effects of setting erosion limits at twice and one times the soil loss tolerance level on income and soil loss were examined. In this analysis it was assumed that operators would continue to use the DC system if it met the lower erosion limits. If disk chisel could not meet those erosion limits it was assumed that operators could purchase, if profitable, sweep equipment that could be used on the HEL soils to be in compliance. This combination of different tillage equipments (disk chisel plus sweep) will be later referred to as "the mixed system".

When the soil loss was restricted to twice the tolerance there was no impact on income or on soil loss in the LER farm. This was because soils on the LER farm already had erosion rates below the 2T level. While on the MER farm the mixed system was used on 520 acres and 80 acres were returned to pasture because erosion could not be reduced below the 2T limit under the mixed system. The net present value of returns fell by 57 dollars per acre. In the MHER farm, 86 acres were returned to pasture and the remaining 514 acres were cultivated by the DC system. The farm value declined by 17 dollars per acre.

The cost of erosion reduction in terms of forgone income depended on the acreage of the highly erodible soils affected by the restriction and on the productivity of those soils which were retired from wheat production. When erosion rates were limited to twice the tolerance the cost per additional ton of soil loss prevented was 0.72, and 0.73 dollars on the MER and MHER farms, respectively.

When soil loss was restricted to the tolerance value, the mixed system was used in all the three farms. The decline in the net present value of returns

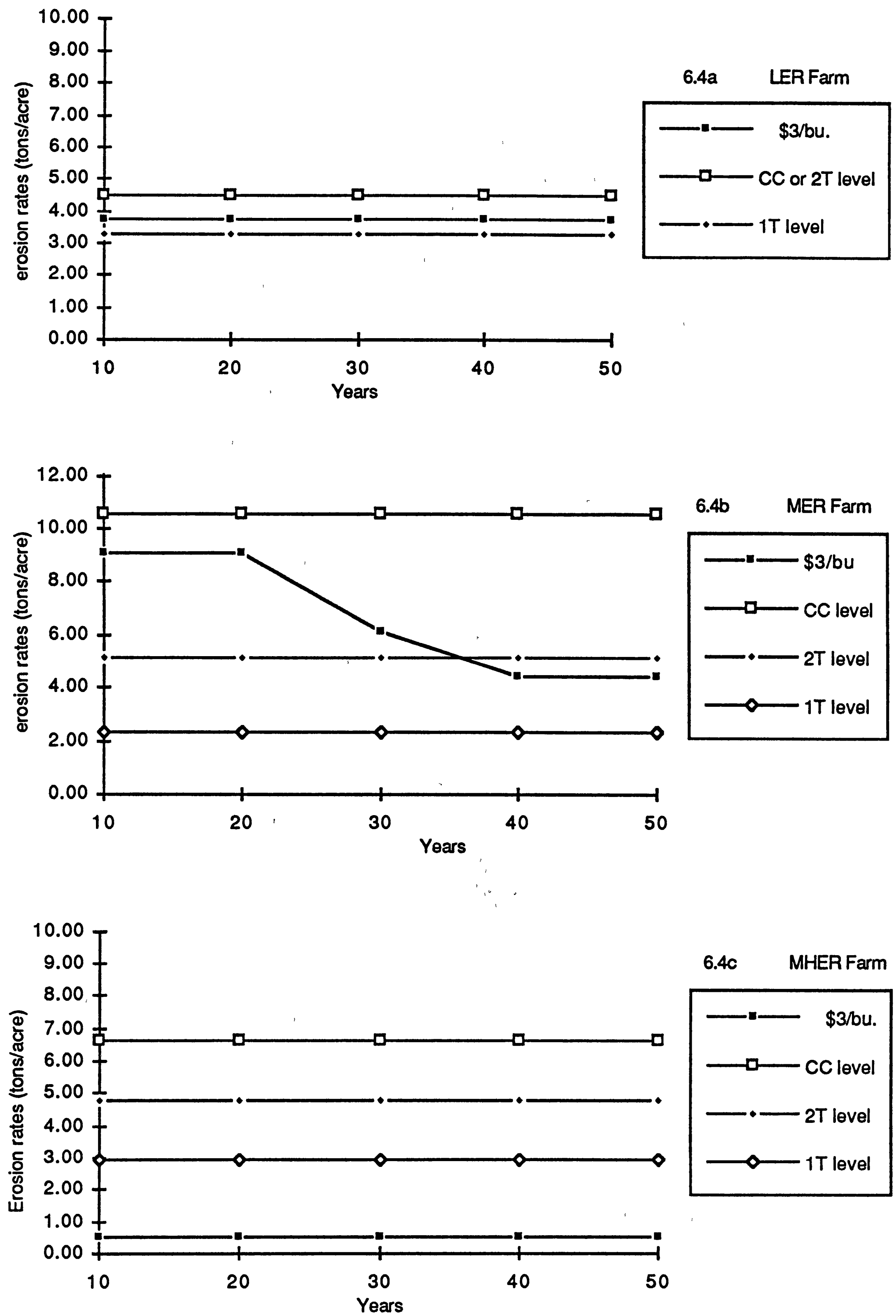


Figure 6.4. Erosion Rates under Market Price and Under Target Price with Three Erosion Control Limits and 8% discount rate.

for the LER, MER, and MHER farms was 31, 148, and 66 dollars per acre, respectively. Figure 6.4 shows the optimal paths of erosion rates for the three farms under market price, and the target price with the three erosion limits. The cost per additional ton of soil loss reduced under 1T limit has risen to 2.08, 3.79, and 2.13 dollars for the LER, the MER, and the MHER farms, respectively.

This section concludes that the cost of further soil loss reduction beyond the CC limits depends on the acreage of HEL affected by the limits and the potential yield of the soil types on the farms. Some farms will incur lower costs than others. Consequently, a uniform policy may not be efficient. Erosion reduction below 2T could be achieved at relatively lower cost per ton of soil loss prevented. Erosion levels below 1T, a level generally referred to as one that would maintain long-term productivity, could be achieved with relatively higher cost in terms of farmer's forgone income.

Optimal Tillage Sequence, Erosion Rates and Farm Income with Erosion Tax

The general result of the preceding analysis was that the value of the loss in soil productivity was not significant enough to justify the adoption of the mixed or the sweep tillage systems. This occurs because the greater costs of the sweep or the mixed tillage systems outweigh the productivity savings from the reduced soil loss when the private discount rate is greater than zero. However, the external costs of soil loss were not included in the analysis. To account for the off-site damage costs a range of erosion charges discussed earlier were used as a measure of off-site damage costs from eroded soil.

Let the optimal solution obtained when the soil loss was restricted to the current CC limit be a reference point (columns 1 to 4 of Table 6.6). We will then examine how tillage systems and farm income changed for each level of erosion charge for each farm situation. Notice that erosion was not constrained when erosion charges were levied. The optimal tillage systems, wheat-pasture mix and income under the three charges for the three farms are presented in Table 6.7.

Erosion Charge of $0.75 Per Ton. As shown in Table 6.7, when an erosion fee of $0.75 per ton was levied there was no change on tillage systems used in the LER farm compared to the current policy of erosion limits on highly erodible soils determined by the SCS guidelines. But the present value (PV) of farm income declined due to the tax payments by 29 dollars per acre (or 8 percent). In the case of the MER farm and the MHER farm a $0.75 per ton charge on soil loss would not affect the farming systems in the short term (10-30 years) but in the long term, as marginal soils erode and their yields decline, the external costs from erosion (or tax payments) would eventually outweigh the profits and the operator would adjust his cropping systems by returning those marginal soils to pasture. The disk chisel remained the most profitable tillage system. Neither the mixed system nor the pure sweep tillage systems were included in the optimal tillage sequence when the erosion tax of $0.75 per ton was assumed, because the additional operating costs were greater than the saving in tax payments. The PV of farm income declined by 68 dollars and 43 dollars per acre for the MER and the MHER farms, respectively. The decline is equal to 15 percent of the total per acre farm value for each farm.

Erosion charge of $1.50 Per Ton. When the erosion fee was assumed to be 1.50 dollars per ton, again there was no change in the optimal tillage systems and wheat-pasture mix in the LER farm. However, the tax payment

TABLE 6.7

OPTIMAL TILLAGE SYSTEMS, WHEAT ACREAGE, PASTURE ACREAGE AND NET PRESENT VALUE OF PROFITS WITH EROSION TAX FOR THREE REPRESENTATIVE GRANT COUNTY FARMS

Erosion tax on dollars per ton	$0.75			$1.50			$2.25		
				LER Farm					
	NPV $/acre 339			NPV $/acre 310			NPV $/acre 282		
Years	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture
1-10	Disk chisel	552	48	Disk chisel	552	48	Disk chisel	552	48
11-20	Disk chisel	552	48	Disk chisel	552	48	Disk chisel	526	74
21-30	Disk chisel	552	48	Disk chisel	552	48	Disk chisel	526	74
31-40	Disk chisel	552	48	Disk chisel	552	48	Disk chisel	526	74
41-50	Disk chisel	552	48	Disk chisel	552	48	Disk chisel	526	74
				MER Farm					
	NPV $/acre 361			NPV $/acre 311			NPV $/acre 280		
Years	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture
1-10	Disk chisel	600	0	Disk chisel	520	80	Sweep Twice	455	145
11-20	Disk chisel	600	0	Disk chisel	455	145	Sweep Twice	455	145
21-30	Disk chisel	600	0	Disk chisel	455	145	Sweep Twice	455	145
31-40	Disk chisel	520	80	Disk chisel	455	145	Sweep Twice	455	145
41-50	Disk chisel	520	80	Disk chisel	455	145	Sweep Twice	455	145
				MHER Farm					
	NPV $/acre 243			NPV $/acre 208			NPV $/acre 178		
Years	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture	Tillage System	Acres in Wheat	Acres in Pasture
1-10	Disk chisel	600	0	Disk chisel	514	86	Disk chisel	451	149
11-20	Disk chisel	600	0	Disk chisel	514	86	Disk chisel	451	149
21-30	Disk chisel	600	0	Disk chisel	514	86	Disk chisel	417	183
31-40	Disk chisel	514	86	Disk chisel	514	86	Disk chisel	417	183
41-50	Disk chisel	514	86	Disk chisel	514	86	Disk chisel	417	183

reduced the PV of returns by 58 dollars per acre or 16 percent. The implication is that if the external cost was $1.50 per ton of eroded soil it still would be both privately and socially optimal to use disk chisel system in the LER farm. The disk chisel was also the socially optimal tillage system to use on the MER and the MHER farms when the erosion fee was assumed to be $1.50 per ton. But, as shown in Table 6.7, the higher erosion fee caused an earlier and a larger acreage retirement of marginal soils from wheat production. The timing of the retirement and the number of acres retired depended on the initial yield, the erosion rate, and erosion's effect on soil productivity. The declines in capitalized returns were 118 dollars (or 26%) and 78 dollars (or 27%) per acre, for the MER and the MHER farms, respectively. The decline in income consists of the tax payments and the reduction in returns due to adjustments in the cropping pattern.

Erosion Charge of $2.25 Per Ton. When the erosion fee was increased to 2.25 dollars per ton the DC system was the most profitable system for the LER and the MHER farms. But in both cases the wheat acreage declined due to lower profits resulting from the yield loss by erosion and the increased tax payment. The LER farm contains highly productive soils with moderate erosion rates under DC system, and the MHER farm contains less productive soils with high erosion rates. In those situations adoption of sweep or mixed tillage systems were not found profitable. In the first case (the LER farm) the operator would turn the relatively small acreage of HEL into pasture as they become less profitable, and use DC for the rest of the farm. While in the second case (the MHER farm) the HEL acreage, which is low in productivity, would not pay to adopt sweep or the mixed tillage system. Again the operator would turn those less productive HEL soils into pasture to minimize erosion tax payments and then would use DC for the remaining acreage. The reduction in PV of income would be 86 dollars (or 23%) per acre for the LER farm and 108 dollars (or 38%) per acre for the MHER farm.

The MER farm had different results when a fee of 2.25 dollars per ton was levied on soil erosion. The sweep tillage system (SWP2) became profitable in this case because the MER farm contains a 255 acres of highly erodible soils of which 110 acres or 18 percent of the farm acreage consists of highly productive soils. The highly productive soils mainly consist of the Grant soil, silt clay loam with 3-5 percent slope, with estimated yield of 32 bushels per acre at the current profile. Hence, the value of the conserved soil plus the savings of the high tax payment made it economical to adopt sweep tillage systems on those soils. While at the same time less productive and highly erodible soils were immediately turned into pasture to minimize the tax payment and receive net positive returns from pasture. The decline in Present value of returns in the MER was 149 dollars per acre (or 32%).

The acreage of Grant soil on the MER farm was parameterized and results are depicted on Figure 6.5. It was found that, when the erosion fee assumed was $2.25 per ton, the sweep tillage system was chosen only when Grant soil constituted more than 10 percent of the farm acreage. Conversely, when the erosion fee was assumed to be $1.50 per ton, the sweep tillage system became more profitable than the DC system only when Grant soil constituted more than 46 percent of the farm acreage. When the erosion tax was assumed to be $.75 per ton, the proportion of Grant soil did not affect the choice of the tillage system. The DC tillage system was the most profitable choice in the later case.

The above analysis concludes that when the off-site damage cost of soil loss is internalized through erosion tax the optimal tillage systems and the cropping pattern (wheat-pasture mix) depended on the level of external costs,

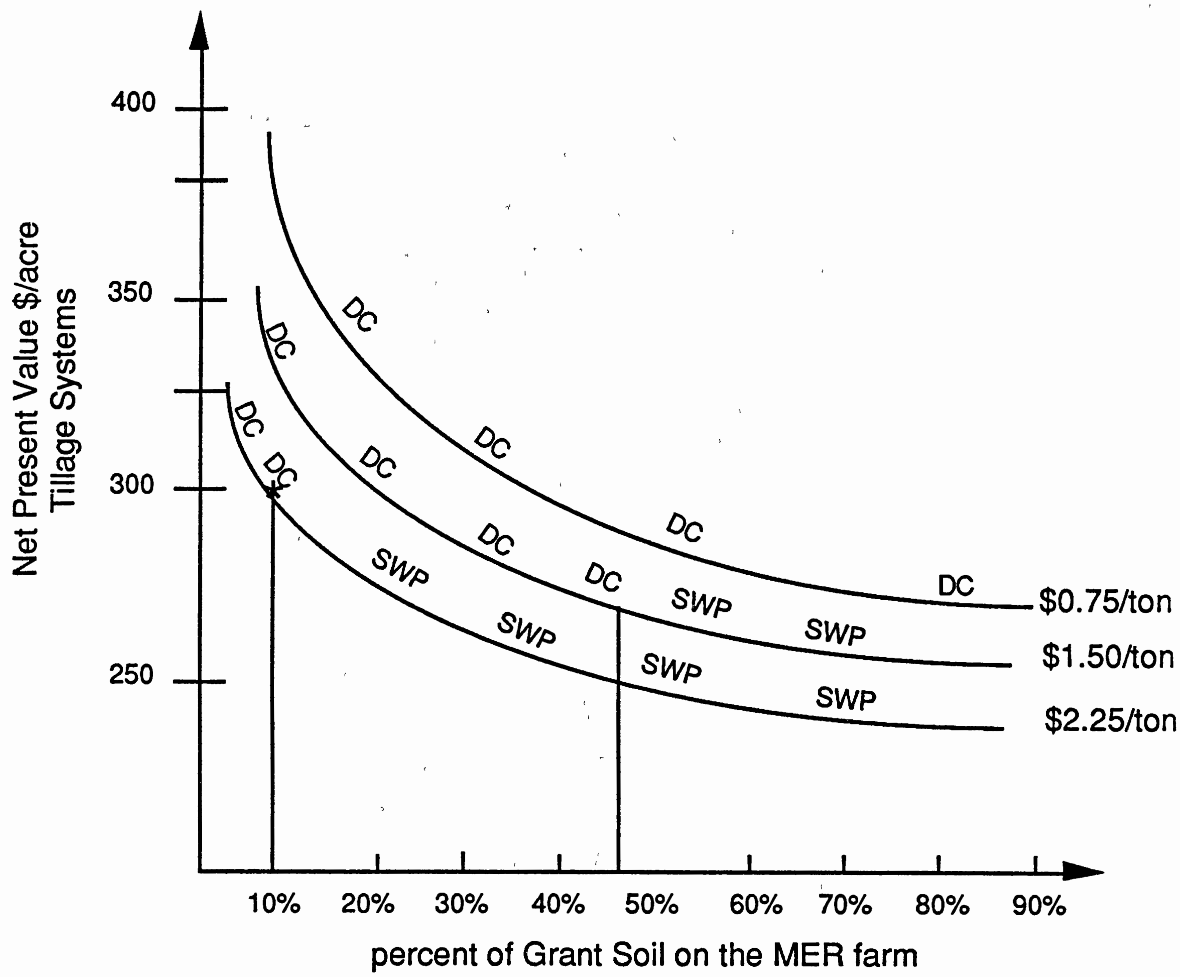


Figure 6.5. Effects of the Soil Mixture on the Choice of Tillage Systems by Erosion Fee.

extent of HEL acres in the farm, and productivity of the highly erodible soils. For the lower values of external costs ($0.75 and $1.50/ton) the DC was the best system for all the three farms. The higher the external cost was, the smaller was the wheat acreage. The timing of retirement and specific soils retired from wheat production depended on the level of external costs, erosion rates and soil productivity. Whereas, for the higher value of external cost ($2.25/ton) sweep tillage systems became profitable on the MER farm which had relatively larger acreage of highly erodible and highly productive soils. While DC still remained the most profitable tillage system on the MHER and LER farms which had a less productive HEL soils or relatively fewer acreage of highly erodible soils.

The analysis demonstrates that erosion charges internalize the external costs of soil erosion but allow the farm operators to either pay the tax or to make internal adjustments in the production systems to reduce erosion. The erosion tax reduced profits more than the erosion limits. Consequently, uniform erosion standards and erosion tax resulted different cropping mix and use of tillage systems. The relative advantage of the two approaches in terms of erosion reduction and cost effectiveness are discussed in the next two sections.

Comparing Erosion Rates Under Direct
Control and Erosion Tax

The erosion rates when soil erosion fees were used varied from those where erosion limits were set. The question to answer herein was which level of the three erosion control limits (CC level, 2T, and 1T levels) will be the most cost effective in reducing a ton of soil of soil erosion when the external damage costs are considered. This analysis is important because it highlights the role of current erosion control standards in reducing off-site damage. There are other programs designed to reduce off-site damage costs such as Conservation Reserve Program (CRP), the Sodbuster, the Swampbuster, and others. But the analysis of these programs are beyond the scope of this dissertation.

Figures 6.6 to 6.8 graphically depict different time paths of erosion rates under the different erosion charges and erosion limits. The results in the figures are discussed next.

The Current CC Erosion Limit. Figure 6.6 shows the optimal paths of soil erosion under the three levels of erosion fees and under the current SCS guidelines on conservation compliance. Figure 6.6 demonstrates that for the farms with the highest proportion of erodible soils (MER and MHER) the current CC erosion limit will produce in the long run erosion rates that are greater than the socially optimal rate of erosion if the external damage from eroded soil is $0.75 per ton or more. The current CC erosion limit, however, will produce erosion rates that are socially optimal on the LER farm if the external cost of soil loss is $1.50 per ton or less. If the external damage from soil erosion was $2.25 per ton the current CC limit will produce erosion rates that are greater than the socially optimal rate of erosion on all three farms.

The 2T Limit. Figure 6.7 shows the optimal paths of erosion rates under the erosion fees and the optimal path of erosion rates when soil loss on HEL soils was restricted to twice the tolerance (2T). Figure 6.7 shows that when the external cost of erosion was assumed to be $2.25 per ton the 2T erosion limit would reduce the soil loss to a socially optimal level in only one case (the LER farm).

When the external damage of soil loss was assumed to be $1.5 per ton the 2T restriction gives erosion rates that were close, but not equal, to the socially optimal levels in all the three cases in the long run. Finally, when the off-site damage from erosion was assumed to be $0.75 per ton the 2T erosion

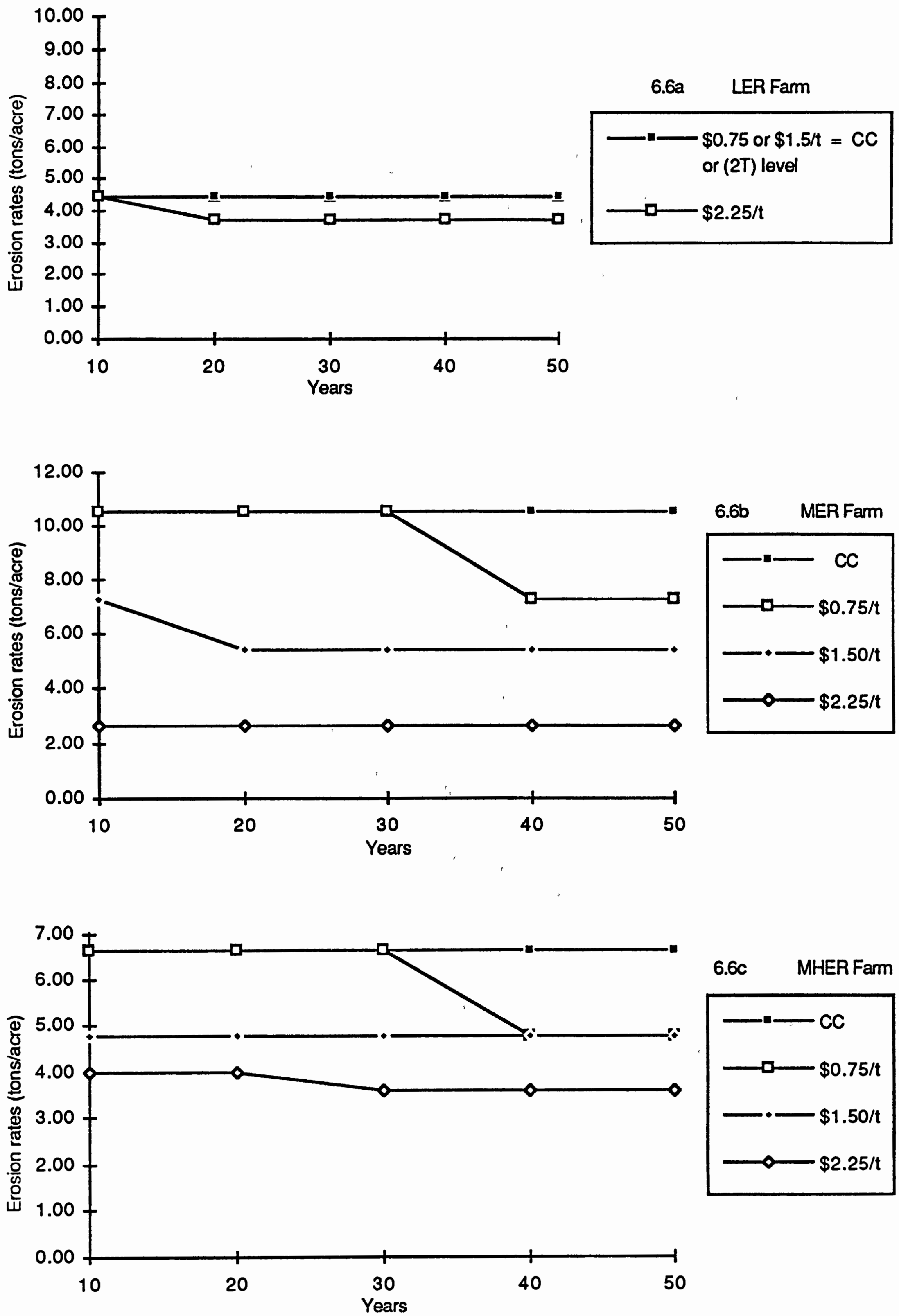


Figure 6.6. Optimal paths of erosion rates under three erosion fees and the CC erosion limit.

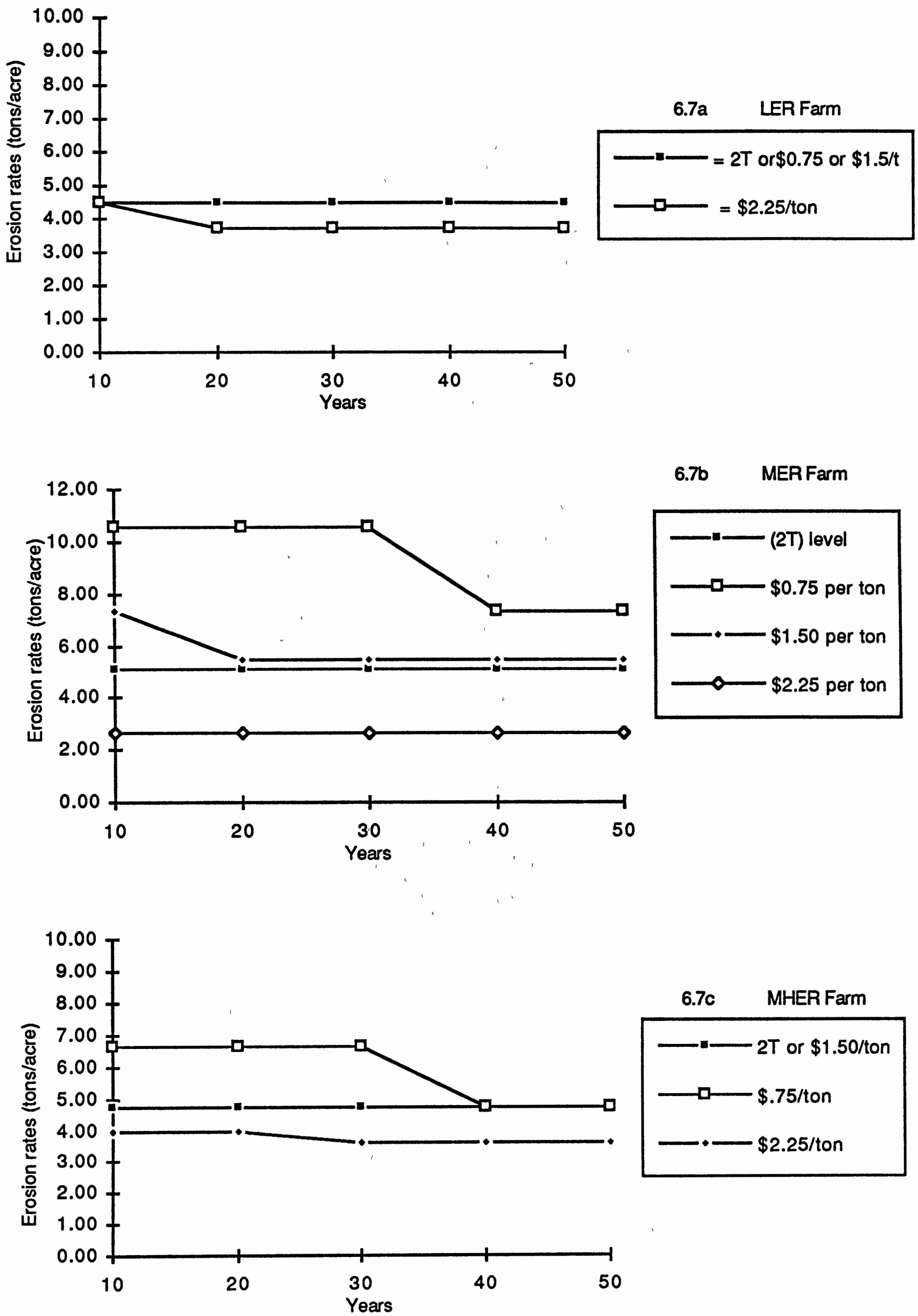


Figure 6.7. Optimal Paths of Erosion Rates Under Three Erosion Fees and the 2T Erosion Limit.

limit was adequate for the LER farm and the MHER farm in the long run. But it was too stringent for the MER farm.

The 1T Limit. Optimal paths of erosion rates under the three erosion fees and under the 1T erosion limit is graphically depicted in Figure 6.8. Figure 6.8 shows that the erosion rates on all the three representative farms were lower when the soil loss was restricted to tolerance value than when an erosion charge of $2.25 per ton or less was assumed. In all the three farms, as shown in the Figure 6.8, the 1T erosion limit is too stringent if the external damage was less than or equal to $2.25 per ton of eroded soil. In other words, the level of erosion control was more than would be socially optimal if the external costs were less than or equal to $2.25 per ton.

One conclusion of the above analysis was that the current SCS guidelines for conservation compliance in the study area would permit HEL soils to erode at rates higher than what would not be socially optimal if off-site damage costs were equal to or greater than $0.75 per ton. Whereas, the soil conservation standard of 1T would be too stringent if the off-site damage costs were less than or equal to $2.25 per ton.

A more general conclusion was that, assuming the above range of external costs of soil erosion, none of the three erosion limits examined, when uniformly imposed on all farms with highly erodible soils, will result in erosion rates that are socially optimal. This occurred because the optimal tillage systems depended upon the extent of highly erodible soils in the farm, the productivity potential of these soils, and the external cost of soil loss that is internalized. All of these factors are farm specific and each operator chooses different wheat-pasture mix and wheat tillage systems that will maximize his

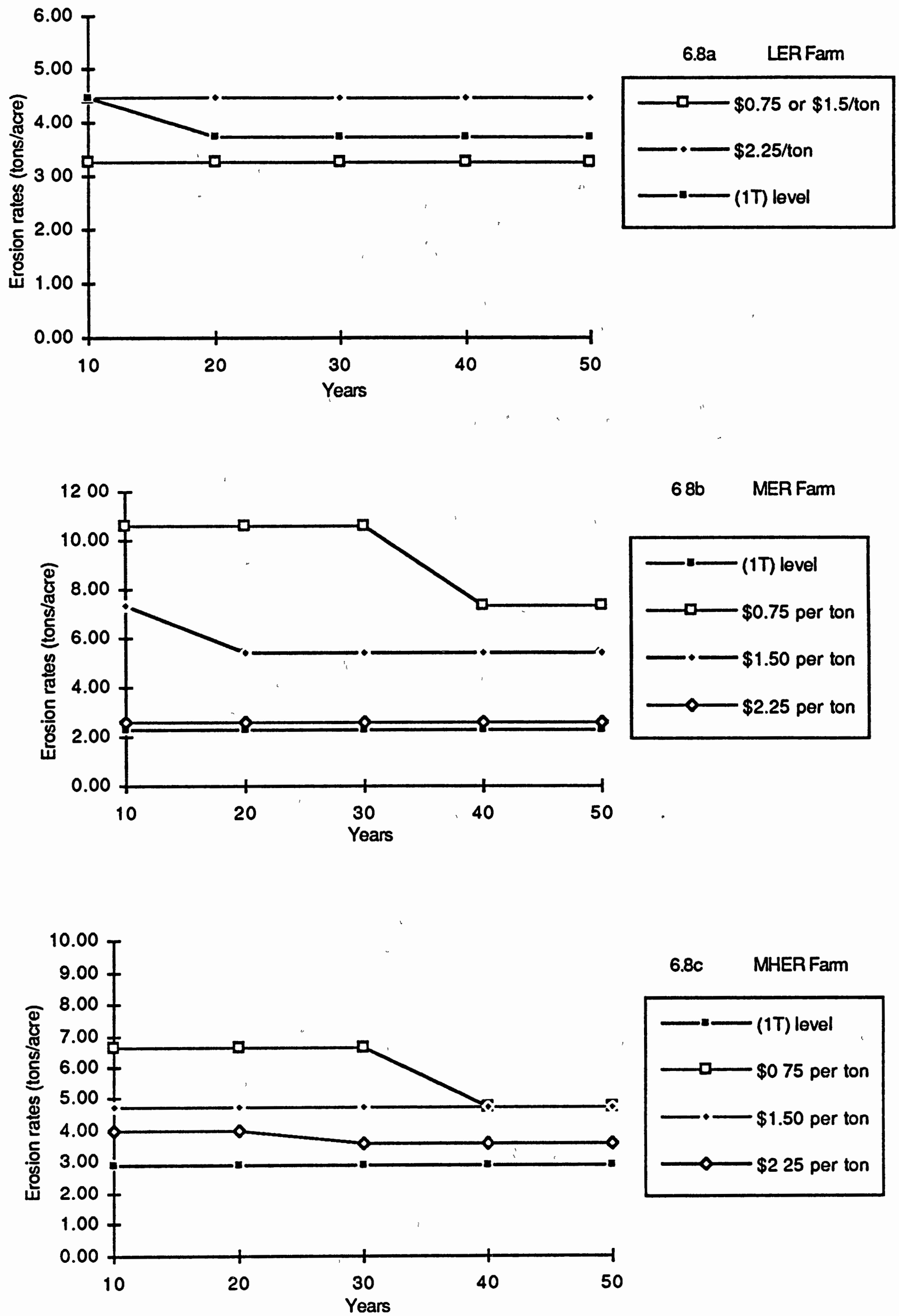


Figure 6.8. Optimal Paths of Erosion Rates Under Three Erosion Fees and the Current 1T Erosion Standard.

profits. The cost effectiveness of erosion charges relative to erosion limits is analyzed next.

Cost-Effectiveness of Erosion Tax

We have so far analyzed the effects of different erosion tax rates and different erosion control standards on choice of tillage systems, on farm income and on erosion rates. In this section we will show that the erosion tax has a cost advantage over the direct control. Costs are the actual economic costs, so tax payments are excluded.

In general any predetermined level of erosion control can be achieved by a well designed erosion tax with a lower cost than by direct control. The proof of this proposition, in a general model can be found in many sources including Fisher (1981), Baumol and Oates (1975), and Tietenberg (1984). Erosion charges have the advantage over the direct control because of allowing each farm operator to adjust in the most efficient way for particular circumstances. By selecting the appropriate tillage system and wheat-pasture mix the operator will indirectly select the erosion rate which equalizes the marginal treatment costs (MTC) and the erosion tax (or estimated marginal damage). While under the direct control farmers have no incentive to curb erosion beyond the limit. If the MTC for each farm is not equal to the marginal damage cost, which would be the case under a uniform erosion standard, same erosion control could be achieved with a lower cost by assigning more erosion control to the lower cost farm and less to the higher cost farm unit the marginal treatment costs are equalized among all farms.

Table 6.8 shows the calculations of erosion control costs for the three farms. Marginal analysis is more appropriate at the soil type level since the

TABLE 6.8

CALCULATION OF COSTS PER TON OF EROSION REDUCED

LER Farm

1	2	3	4	5	6	7	8	9
	NPV Total Returns ($/ac)	NPV Tax Payment ($/ac)	NPV Farmer's Returns ($/ac)	Average Erosion Rates (t/ac)	PV Total Cost of Treatment ($/ac)	Total Reduced Erosion (t/ac)	Percent of Reduced Erosion (%)	Marginal Social Cost of Treatment ($/ton)
Direct control:								
CC level	368	0	368	4.47	0	0.00	0	-
2T level	368	0	368	4.47	0	0.00	0	-
1T level	337	0	337	3.28	31	1.19	27	2.08
Er.Tax/ton:								
$0.75	368	29	339	4.47	0	0.00	0	-
$1.50	368	58	310	4.47	0	0.00	0	-
$2.25	362	80	282	3.38	6	1.09	24	0.44

MER Farm

	PV Total Returns ($/ac)	PV Tax Payment ($/ac)	PV Farmer's Income ($/ac)	Average Erosion Rates (t/ac)	PV Total Cost of Treatment ($/ac)	Total Reduced Erosion (t/ac)	Percent of Reduced Erosion (%)	Marginal Social Cost of Treatment ($/ton)
Direct control:								
CC level	429	0	429	10.54	0	0.00	0	-
2T level	372	0	372	4.23	57	6.31	60	0.72
1T level	281	0	281	2.31	148	8.23	78	3.79
Er.Tax/ton:								
$0.75	427	66	361	9.24	2	1.30	12	0.12
$1.50	394	83	311	5.81	35	4.73	45	0.77
$2.25	331	51	280	2.63	98	7.91	75	1.58

MHER Farm

	PV Total Returns ($/ac)	PV Tax Payment ($/ac)	PV Farmer's Income ($/ac)	Average Erosion Rates (t/ac)	PV Total Cost of Treatment ($/ac)	Total Reduced Erosion (t/ac)	Percent of Reduced Erosion (%)	Marginal Social Cost of Treatment ($/ton)
Direct control:								
SCS level	286	0	286	6.62	0	0.00	0	-
2T level	269	0	269	4.76	17	1.86	28	0.73
1T level	220	0	220	2.92	66	3.70	56	2.13
Er.Tax/ton:								
$0.75	285	42	243	5.88	1	0.74	11	0.11
$1.50	269.	61	208	4.76	17	1.86	28	1.14
$2.25	254	76	178	3.75	32	2 87	43	1.19

operator decides whether to cultivate each soil type or to leave it under pasture. However, the table contains weighted average values for the farm. As a result marginal treatment costs do not directly correspond to the erosion charges. Nevertheless, Table 6.8 demonstrates that the marginal cost of erosion control, in terms of present value of forgone income, is an increasing function of the quantity reduced (see columns 8 and 9 of Table 6.8).

To compare the relative cost effectiveness of erosion charges and the direct control let us assume that a public authority wants to reduce the soil erosion of the study area by either using direct control approach through limiting the soil loss to the T level or charging an erosion fee of $2.25 per ton. These two scenarios were selected because their erosion reduction effects were the closest among all other scenarios for all the three farms. Table 6.9 contains the percentage of erosion reduced, total costs, and average costs under the two options for the three farms. Notice that the erosion reduction was not equal for the two scenarios so the comparison is not exact. But the difference is small and may not greatly affect the results.

As shown in Table 6.9 in all the three farms the erosion charge had the least average cost per ton of soil erosion reduced. The capitalized net social losses from using the tolerance value as a uniform erosion control standard instead of charging a uniform erosion fee of $2.25 per ton were $21, $6, and $7 per ton of soil erosion prevented for the LER, MER, and MHER farms, respectively. The sum of these values could be significantly large in a large scale area like a watershed where soil is being eroded from hundreds of farms. An important difference between the two approaches, however, was their impacts on the farmer's income. When the tax of $2.25 per ton of soil erosion was charged, the decline in the net present value of private returns per acre

TABLE 6.9

TOTAL AND AVERAGE SOCIAL COSTS OF EROSION CONTROL BY EROSION STANDARDS AND BY EROSION TAX FOR THREE REPRESENTATIVE FARMS[1]

	Policy					
	1T level			Erosion on charge of $2.25/ton		
	Farms			Farms		
	LER	MER	MHER	LER	MER	MHER
Percent Erosion Reduction	27	78	56	24	75	43
Decline NPV Social Returns ($/ac)	31	148	66	6	98	32
Capitalized Tax Payment ($/ac)	–	–	–	80	51	76
Percent decline in NPV private returns	8.4	34.5	23.1	23.4	34.7	37.8
Decline in Social NPV Per Ton	26.1	18.0	17.8	5.5	12.3	11.2
Average Annual Social Cost ($/TAY)[2]	2.08	1.44	1.43	.44	.99	.89

1 Discount rate used is 8 percent.

2 TAY = tons per acre per year of reduced erosion.

were 15.0, 0.3, and 14.7 percent greater than the declines of the net present value of private returns per acre under the 1T level of erosion limit.

In this section, by using the results of the dynamic farm models, it has been empirically shown that for a given level of erosion control an erosion charge will have a lower cost per unit of erosion reduced than direct erosion limits. But erosion tax will have a greater negative impact on farmer's profits than the direct erosion limits.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The purpose of this research was to assess whether it would be in the long-term interest of private producers and the society to adopt the conservation tillage systems for wheat in Grant County Oklahoma. Specific objectives were to:

1) Compare the long-term profitability of alternative tillage systems for wheat on different soil types in the study area.
2) develop a dynamic economic model of soil conservation and to use this model to determine the private optimal sequence of tillage systems for wheat on representative farms in the study area.
3) determine the effects of discount rates, technology, and soil conservation policy on the optimal solutions of the model.
4) determine the relative cost-effectiveness of direct erosion control and erosion tax in preventing a ton of soil loss.

In Chapter 2, the soil erosion problem, its measurement and impact were discussed. The literature on the impact of soil erosion on productivity was reviewed. The external damage of soil erosion was also discussed in that chapter.

In chapter 3, the theoretical framework for an optimal management of non-renewable natural resources was covered. Necessary conditions for optimal resource use were derived using a discrete-time as well as a continuous-time framework.

In chapter 4 a dynamic soil erosion model was developed and an empirical model was formulated for the representative farms in the study area. The components of the objective function and constraints were explained. The objective function was to maximize the discounted net returns to land, risk, overhead and management for a 600 acre farm containing different soil types over a 150 year period. The 150 year period was divided into a 50 year planning horizon and a 100 year period which was used to estimate the farm resale value at the end of the planning horizon. The constraints of the empirical models were: an equation of motion on soil depth for each soil type on a representative farm, which updated soil depth at each time period, a constraint on the use of the soils on the farm on either wheat or pasture, and a constraint on the total acreage of the farm.

In chapter 5, the data requirements, procedures used for simulating yields and erosion rates and estimation of yield-soil depth response functions were described. In that chapter, the three representative farms used in this study were described. Each representative farm had six to eight different soils. The total acres of highly erodible land on the farm was hypothesized to be an important factor affecting the choice of tillage systems for wheat. The three representative farms were described as less highly erodible (LER), moderately highly erodible (MER), and mostly highly erodible (MHER) depending upon the extent of the HEL acreage on the farms.

In chapter 6, the analysis, assumptions, and results were discussed. The analysis was two fold: an analysis by individual soil type and a farm level analysis. Estimates of the net present value of returns to land per acre for 150 years of continuous wheat production for all soil map units under four tillage systems were presented. The market price of wheat was assumed to be $3.00 per bushel and the target price was assumed to be $4.00 per bushel for a producer participating the commodity programs. The results of a dynamic programming (DP) analysis for selected HEL soils were also presented in chapter 6. A total of 45 scenarios were analyzed for the three representative farm models. Under the market price scenario there were 3 discount rates and 3 annual technological growth rates. Under the target price scenario there were 3 levels of soil erosion limits and 3 levels of erosion charges. So, there were 15 scenarios for each representative farm.

Conclusions

It was found that the net present value of returns discounted at 8.25 percent for the disk chisel system was higher than for the other tillage systems on all soil map units regardless on whether or not the producer participated in the commodity program. The results indicated, however, that a larger proportion of the HEL area would be planted to wheat in the presence of the commodity program than would be planted if producers received only the expected market price of $3.00 per bushel for their wheat. The results of the DP analysis, where only private erosion costs were considered, indicated that it would be necessary to have capitalization rates of less than two percent for producers to adopt reduced tillage systems on class II, III, IV, and VI soils.

The results of the farm level analysis is summarized as follows:

A) With the Market Price

1) Wheat producers farming HEL (for example land similar to the LER and MER farms) in Grant County who produce outside the commodity program, at all discount rates, will find

the disk chisel the most profitable tillage system. Producers farming marginal soils (like the MHER farm) will find pasture as a better option.

2) At market price, when only private erosion costs are considered, farmers will find sweep tillage systems more profitable than disk chisel only if they have a zero discount rate and have positive expectations about future yield increment due to technological advance. However, when positive discount rates (4% and 8%) and an annual yield growth of 0.7% and 1.4% were assumed, the DC was again the most profitable tillage system in all the three representative farms. Technological progress increased the rate of soil depletion on all the three farms because more marginal soils were cultivated and the incentives for conservation due to future yield growth were reduced by the increased discount rates.

B) With the Target Price

1) As mentioned above in the individual soil analysis, DC became the most profitable tillage system when the target price of $4 per bushel was assumed at 8 percent discount rate. Net present value of returns per acre increased by 235, 261 and 200 dollars for the LER, MER and MHER farms, respectively. Erosion rates were, of course, greater under the target price because the higher price made it profitable to farm the more marginal land for longer periods of time.

2) Although the DC tillage system meets the conservation compliance (CC) requirements for all soils on the representative farms, it would erode some HEL erodible soils to the point where wheat is no more profitable in 20-30 years at the market price. The cost of further soil loss reduction beyond the CC limits depended on the soil mixture of the farms. When erosion was restricted to be less than 2T the estimated annual cost was $.73 and $.93 per additional ton of soil loss prevented for MER and MHER farms. When the soil erosion was restricted to less than 1T the estimated annual cost was $2.08, $3.76 and $2.13 per additional ton of soil erosion prevented for the LER, MER and MHER farms, respectively.

3) The results also indicated that if the external cost of soil loss is less than or equal to $2.25 per ton, a policy that restricts soil loss to less than 1T would be too stringent. Conversely, if the external cost of soil loss is greater than or equal to $.75 per ton, a policy requiring the conservation compliance alone would allow erosion rates that are greater than what would be socially optimal.

4) Finally, the results showed that an erosion tax would have a lower average social cost per ton of soil erosion reduced than the direct control erosion limits with comparable levels of erosion reduction. But an erosion tax would have a greater negative impact on the farmer's profits than erosion limits.

In summary, the results of the study indicated that participation in the commodity programs, where wheat producers in the study area receive a target price of $4 per bushel, without considering the external damage of soil loss, results in the adoption of the DC tillage system. The DC tillage system meets the requirements of the conservation compliance. However, the DC tillage system will not maintain economic yields in the long-run on some highly erodible soils in the study area. The DC tillage system also generates erosion rates that are greater than the socially optimal rates of erosion when external damage of soil erosion is $0.75 per ton or more.

The implication of these results is that a soil conservation policy that reduces soil erosion below the current rates will be necessary if the external cost of soil erosion in the study area is $0.75 per ton or more. The more restrictive erosion standards will require farmers to either adopt conservation tillage systems on HEL soils or return these soils to pasture. If wheat production becomes more profitable than pasture, farmers will either use a mixed tillage system (DC + Sweep) or a pure sweep tillage system depending on the erosion restriction imposed and the extent of HEL acreage which are affected. Although the more restrictive policy reduces farm income, farmers will still receive higher net present value of returns to land by participating in the commodity program than by choosing to produce outside the commodity program.

The results of this study also indicate that agricultural price and income support programs similar to the commodity programs like the export enhancement program or other programs that encourage acreage expansion, without restricting the rates of soil erosion, produces higher erosion rates than be the case without those programs. A socially efficient use of soil resources requires that those programs consider the costs of the long-term losses in soil productivity from the higher rates of soil depletion and the costs of the external damages of soil erosion.

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APPENDIXES

APPENDIX A

ESTIMATED COEFFICIENTS AND STANDARD ERRORS OF THE MAJOR SOIL SERIES OF GRANT COUNTY

Soil		Ln(B)	Ln(r)	Buse-R squared[1]
Attica	FSL	2.1329 (0.0316)	-0.39336 (0.0173)	0.48
Dale	SIL	1.3553 (0.0931)	-0.083 (0.045)	0.21
Goodnight	LFS	2.1428 (0.087)	-0.41198 (0.0415)	0.33
Grainola	SICL	1.76219 (0.0115)	-0.4282 (0.0217)	0.50
Grant	SIL	1.87574 (0.041)	-0.53711 (0.025)	0.50
Kingfisher	SIL	1.7812 (0.0117)	-0.55972 (0.0196)	0.68
Port	SIL	2.7233 (0.032)	-0.8153 (0.0215)	0.32
Kirkland	SIL	2.1308 (0.0283)	-0.51116 (0.0251)	0.55
Port	SICL	2.3141 (0.0241)	-0.915 (0.0413	0.34
Norge	SIL	1.8525 (0.0325)	-0.36154 (0.0213)	0.30
Oscar	SIL	1.445 (0.0215)	-0.0215 (0.0062)	0.24
Pondcreek	SIL	1.8387 (0.0966)	-0.32214 (0.0511)	0.20

Pratt	LFS	1.9657 (0.0237)	-0.29329 (0.0162)	0.30
Quinlan	L	1.7461 (0.047)	-0.18496 (0.0161)	0.60
Woodward	L	1.80248 (0.0433)	-0.3707 (0.0521)	0.40
Renfrow	SICL	1.77212 (0.0406)	-0.30411 (0.022)	0.30
Renfrow	SIL	1.6759 (0.0338)	-0.3147 (0.022)	0.20
Shellaberger	FSL	2.6641 (0.0324)	-0.7286 (0.0213)	0.65

[1] Buse-R squared is a goodness-of-fit measure which takes into account the GLS nature of the model. Refer to Buse, A. "Goodness of Fit in Generalized Least Squares Estimataion", Amerian Statistician, 27(1973):106-08.

APPENDIX B

THE GAMS PROGRAM OF THE EMPERICAL MODEL FOR THE LER FARM

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*This GAMS model maximizes the net pesent value of returns
* With price of $4.0 per bushel and erosion restricted to
*  the soil loss tolerance value (TVAL)
* Erosion is estimated on a per acre basis
* System fixed cost is estimated for each investment period
*      (10 years)
* Yields are estimated by the Spillman type function

SETS
 S soils /Beth,Kirk1,Mclain,Drummond,Kingf1,Kirk2,kingf2,pondc/
  T time periods /1*16/
  TE(T) use periods
  TCE cropsequipment /WDisk, DSKSWP, WSwep, Past/
  CE(TCE)  wheat only
  ;

ALIAS (T,YR);
  TE(T) = YES$(ORD(T) LT CARD(T));
  CE(TCE) = YES$( ORD(TCE) LT CARD(TCE));

  DISPLAY TE;
SCALAR  DISCR/.08/
        YMUL the 10-year period multiplier/10/
        TECH factor for yield increament/0.00/
        TVAL soil loss tolerance valuein meters/.007/;

PARAMETER DISCF;
          DISCF=1/(1+DISCR);
PARAMETER TIME(T), DISC(T), TECHF(T);
        TIME(T) = ORD(T);
        DISC(T)=DISCF**(YMUL*TIME(T));
        TECHF(T)=EXP(TECH*YMUL*TIME(T));
DISPLAY TIME, DISC;

PARAMETERS
   BO(S) is the M coefficient in Mitcherlich-Spillman function
                 /Beth      2.62158
                  Kingf1    6.00
                  kingf2    6.00
                  Kirk1      6.00
                  Kirk2      6.000
                  Mclain     2.82324
                  Drummond  1.07552
                  Pondc      6.00000/
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```
B1(S) is the B coefficient
                / Beth          0.00000
                  Kingf1        5.93
                  kingf2        5.93
                  Kirk1         8.4
                  Kirk2         8.4
                  Mclain        0.00
                  Drummond      0.00
                  Pondc          6.3/
B2(S) is the r coefficient
                / Beth          0.00000
                  Kingf1       -0.55972
                  kingf2       -0.55972
                  Kirk1        -0.51116
                  Kirk2        -0.51116
                  Mclain        0.00
                  Drummond      0.00
                  Pondc        -0.32214/

YLDF(S) factor used to aline EPIC yields with SCS expected yields.
                 /Beth          1.003
                  Kingf1        1.101
                  kingf2        0.972
                  Kirk1         0.87
                  Kirk2         0.799
                  Mclain        0.775
                  Drummond      0.867
                  Pondc         1.091/

BD(S) beginning soil depth (meters) for each soil
                / Beth          1.829
                  Kingf1        0.737
                  kingf2        0.737
                  Kirk1         1.829
                  Kirk2         1.829
                  Mclain        1.905
                  Drummond      1.524
                  Pondc         1.829/

AC(S) area of each soil in acres
                / Beth          99
                  Kingf1        39
                  kingf2        26
                  Kirk1        130
                  Kirk2        132
                  Mclain        70
                  Drummond      48
                  Pondc         56/

FC(TCE)  FIXED COST PER 600 ACRES FOR 10 YEARS
                      /WDISK  125640
                       DSKSWP 132619
                       WSWEP  117720/
                      ;
```

```
TABLE VVC(S,TCE) per acre system variable costs in a decision
period
                              WDISK      DSKSWP     WSWEP
                 Beth         661.4       661.4      756.5
                 Kingf1       661.4       661.4      756.5
                 Kingf2       661.4       756.5      756.5
                 Kirk1        661.4       661.4      756.5
                 Kirk2        661.4       756.5      756.5
                 Mclain       661.4       661.4      756.5
                 Drummond     661.4       661.4      756.5
                 Pondc        661.4       661.4      756.5;

TABLE EROC(S,TCE) are eroded depth for 10 years by each system
                          WDISK      DSKSWP    WSWEP         PAST
            Beth          .0046      .0046     .0021         .0010
            Kingf1        .0057      .0057     .0031         .0005
            kingf2        .0132      .0069     .0069         .0005
            Kirk1         .0044      .0044     .0021         .0005
            Kirk2         .0104      .0051     .0051         .0005
            Mclain        .0041      .0041     .0017         .0005
            Drummond      .0028      .0028     .0012         .0005
            Pondc         .0051      .0051     .0025         .0010
             ;
* Price per bushel is multiplied by (1/.06722) and 10 to change
*   into dollars per acre for 10 years
             SCALARS PPST/100/
                     PW/572.7/
                     ;
PARAMETER ACR(T,S), VC(T,S,TCE);
        ACR(T,S)=AC(S);
        VC(T,S,CE)=VVC(S,CE);

*Remainig depth is calculated by subtracting the erroded
* depth from the current depth
PARAMETER RD(T,S), ERO(S,TCE),SOLT(T,S), YLF(T,S);
      ERO(S,TCE) = EROC(S,TCE)/AC(S);
      RD(T,S) = BD(S);
      YLF(T,S)=YLDF(S);
DISPLAY ERO;

PARAMETER CER(T,YR,S,TCE);
  CER(T,YR,S,TCE) = ERO(S,TCE)$( ORD(T) GT ORD(YR));
  DISPLAY CER;

VARIABLES  NDPR,  A(T,S,TCE), YLD(T,S),SY(T,TCE), DPTH(T,S);
POSITIVE VARIABLES A(T,S,TCE), YLD(T,S), SY(T,TCE), DPTH(T,S);
EQUATIONS  PRDF, PRD(T,S), LND(T,S), EQIP(T), RDPTH(T,S);

LND(T,S)..  SUM(TCE,A(T,S,TCE)) =L=  ACR(T,S);
EQIP(T)..  SUM(CE, SY(T,CE)) =L= 1;
```

```
RDPTH(T,S).. DPTH(T,S)=E=RD(T,S)-SUM((YR,TCE),A(YR,S,TCE)*
                              CER(T,YR,S,TCE));

PRD(T,S).. YLD(T,S) =E= YLF(T,S)*(BO(S)-B1(S)*EXP(B2(S)*
                             DPTH(T,S)))*TECHF(T);

PRDF..  NDPR =E= SUM(TE,DISC(TE)*(
                  SUM(CE,
 (SUM(S, (PW*YLD(TE,S) - VC(TE,S,CE) ) *A(TE,S,CE) )- FC(CE))*
                             SY(TE,CE)
                             )
             +SUM(S, PPST*A(TE,S,'PAST')) )
                             );
MODEL FARM12 /ALL/;

* This par pf the program is to initialize the variables
* Soils that have erosion rates higher than the tollerance level
*   under DC are constrained not to be cultivated by DC

A.UP(T,S,CE) = AC(S);
A.LO(T,S,CE) = 0;
A.FX(T,'KIRK2','WDISK')=0;
A.FX(T,'KINGF2','WDISK')=0;
A.FX(T,'DRUMMOND','PAST')=48;

A.FX(T,S,'WSWEP')=0;
A.L(T, 'Beth', 'WDISK')=33;
A.L(T,'KINGF1','WDISK')=13;
A.L(T,'KINGF2','WDISK')=9;
A.L(T, 'KIRK1','WDISK')=43;
A.L(T,'KIRK2','WDISK')=44;
A.L(T,'MCLAIN','WDISK')=23;
A.L(T,'DRUMMOND','WDISK')=16;
A.L(T,'PONDC','WDISK')=19;

A.L(T, 'Beth', 'DSKSWP')=33;
A.L(T,'KINGF1','DSKSWP')=13;
A.L(T,'KINGF2','DSKSWP')=9;
A.L(T, 'KIRK1','DSKSWP')=43;
A.L(T,'KIRK2','DSKSWP')=44;
A.L(T,'MCLAIN','DSKSWP')=23;
A.L(T,'DRUMMOND','DSKSWP')=16;
A.L(T,'PONDC','DSKSWP')=19;

A.L(T, 'Beth', 'WSWEP')=33;
A.L(T,'KINGF1','WSWEP')=13;
A.L(T,'KINGF2','WSWEP')=9;
A.L(T, 'KIRK1','WSWEP')=43;
A.L(T,'KIRK2','WSWEP')=44;
A.L(T,'MCLAIN','WSWEP')=23;
A.L(T,'DRUMMOND','WSWEP')=16;
A.L(T,'PONDC','WSWEP')=19;
```

```
SY.L(T,'WDISK') =  .2;
SY.L(T,'DSKSWP') = .8;
SY.L(T,'WSWEP')  =  0;

SOLVE FARM12 USING NLP MAXIMIZING NDPR;

* This prat of the Program is to provide a summary of the results
PARAMETER ACRES, PROFIT, YLDD, DEPTH  PFINAL SOLUTION VALUES;
   ACRES(TE,S,TCE)=A.L(TE,S,TCE);
   YLDD(TE,S)= YLD.L(TE,S);
   DEPTH(TE,S)=DPTH.L(TE,S);
     PROFIT=NDPR.L;
DISPLAY PROFIT, ACRES, YLDD, DEPTH;
```

VITA

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