OPTIMAL NITROGEN AND CHOICE OF REDUCED TILLAGE SYSTEMS FOR WHEAT PRODUCTION IN NORTH WESTERN OKLAHOMA

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DC	Disk Chisel
Kirdc	Kirkland with disk
Kirpl	Kirkland with plow system
Kirsw1	Kirkland with sweep system once
Kirsw2	Kirkland with sweep system twice
NPV	Net Present Value
PL	Plow system
Rendc	Renfrow with disk chisel
Renpl	Renfrow with plow system
Rensw1	Renfrow with sweep system once
Rensw2	Renfrow with sweep system twice
SW1	Sweep system once
SW2	Sweep system twice

CHAPTER I

INTRODUCTION

Problem Statement

Since the 1930's, soil erosion has been a concern for society. A survey by the Soil Conservation Service (SCS) in 1977 showed that on a quarter of the nation's cropland, sheet and rill (water) erosion exceeded 5 tons per acre, the maximum consistent with indefinite maintenance of soil productivity on most soils. Soil erosion causes two types of damages. The first is a loss in productivity or crop yields. Continuous erosion removes plant nutrients, causes thinning of soils and changes its desirable physical, biological and chemical properties, jeopardizing long-term sustainability of high levels of food and fiber production. Studies cited by Lyles (1975) showed that on the average, erosion reduced wheat yield by more than 5% per inch reduction in soil depth in many crop areas of the United States, including Oregon, Ohio, Washington, and Kansas.

The second type and the greater cost of damages from soil erosion are the off-farm pollution of air and water, and accelerated sedimentation of canals, lakes, and reservoirs. As a result of erosion, soil particles and soil nutrients increase the turbidity of water and stimulate algae growth in lakes and reservoirs. Recreational values are reduced as boating, fishing, and swimming are impeded. Drinking water treatment costs are increased because eutrophication gives water an unpleasant appearance and a bad odor.

Clark et al. (1985) estimated that soil erosion from all sources caused $6.1 billion annually to in-stream facilities and off-stream water uses from which $2.2 billion was attributed to cropland erosion.

Research during the 1970's indicated that the most cost-effective means of reducing soil erosion and its damages was with conservation tillage systems (USDA, 1980). The producer's incentive to adopt conservation practices, that reduce both on-and off-site damages of soil from soil erosion, depends mainly on short and long-term profits from the reduction of on-site damages. This depends on crop yields, rate of erosion, and tillage costs. Incentives to reduce off-site damages have been historically relayed to the producer through cost sharing and more recently by the conservation compliance requirements for participation in federal commodity programs.

Farm level comparisons between conservation and conventional tillage systems typically involve a trade-off between lower machinery-related costs but higher chemical and/or fertilizer costs for the former. The reduced tillage systems may be more profitable in the long run, but producers may favor short run profit. This conflict becomes important because of the risk behavior involved particularly when higher expected returns are generally accompanied by higher variance of returns. Almaras (1990) pointed out that even with improvement of tillage there remain wide ranges of technological deficiencies, which increase the risk of failure.

Many studies have attempted to determine the optimal use of alternative tillage systems under both risk and non-risk averting behavior. Aw Hassan (1992) conducted a long-term analysis of the impact of wheat tillage systems on soil erosion and private and social returns in north central Oklahoma. Lee, Brown, and Lovejoy (1985) compared stochastic efficiency and mean-variance criteria as predictors of adoption of tillage systems. Klemme (1983) used stochastic dominance analysis to compare reduced tillage systems in corn and soybean production under risk. The optimal tillage system varies from one study to another. In the Aw Hassan study, the disk chisel system had the highest private net present value of returns for all soils. Klemme's results indicate that farmers choose conventional no-till systems only when soil costs are not assigned. Riskaverse farmers who place low values on soil losses may select these systems. An annual per hectare soil cost of $12.5 to $37.5 shifts ranking toward the advantage of reduced tillage systems.

The determination of the optimal use of conservation tillage systems is complicated by the impact of technical progress on crop yields. Erosion is a gradual process. The annual yield gains from technological advances and the variability caused by weather, disease, and pests can mask the reduction of crop yields from soil loss. While technical progress has boosted crop yields faster than erosion has reduced them, Walker and Young (1986) demonstrate that this effect may be short-term. Some types of technical progress can actually increase erosion damage. Walker and Young indicate that land-complementary technological progress is represented by improved crop cultivars, boosts yield at deeper topsoil depth. A land substituting-technology, as in the case of tillage improvements to conserve soil moisture, boosts the yield function at shallower topsoil depth.

Many studies concerning farmers' choice of tillage systems to reduce soil erosion have based their assessment of erosion damage on the effect of tillage systems without taking into account the interaction between technological change, nutrient management, and conservation practices. In most studies the effects of tillage systems have been analyzed holding fertilizer level constant, resulting in a parallel shift of the production function for changes in soil depth. In many cases the studies have not integrated the effect of nitrogen changes on off-site damages.

Objectives

The objective of this research is to determine the optimal use of conservation techniques and commercial fertilizer to maintain productivity of soil in Garfield County, Oklahoma subject to limitations of offsite damages from soil erosion and fertilizer losses.

The specific objectives are:

1. estimate the functions of yield, erosion, nitrogen loss, and residual nitrogen by soil type and or tillage system used
2. determine the rate at which conservation techniques such as reduced tillage and commercial fertilizers substitute for each other to enhance or maintain soil productivity
3. determine the sensitivity of optimal temporal choices with respect to fertilizer application and adoption of reduced tillage techniques that maximize expected returns from crop production in the study area to:
    a. changes in crop, fertilizer, and herbicide prices
    b. discount rates
    c. value of per unit offsite damages from soil erosion and fertilizer nutrients in surface and ground water.

4. evaluate and compare alternative methods of solving for the temporal use of tillage systems and fertilizer that gives the maximum net present value.

The study will determine optimal temporal use of nitrogen and tillage systems that maximizes discounted private and discounted social returns. The consideration of nitrogen use in relation to soil conservation is important because farmers often respond to a yield decrease by increasing nitrogen use that, according to Walker and Young (1986), underestimates erosion damage. Farmers have little incentive to reduce off-site damages because of the relatively cheap price of nitrogen. They may find it more profitable to use more fertilizer than adopt conservation tillage systems. This study will determine how producers will substitute fertilizer for tillage systems or soil depth.

CHAPTER II

SOIL EROSION AND CONSERVATION RESEARCH

Soil Erosion assessment

Soil erosion is the process of detachment and transportation of soil particles by an erosive agent. The erosive agents are raindrops and surface runoff for sheet and rill erosion and wind for erosion by wind. Soil erosion is a continuously occurring natural process. However, human activities like cutting and clearing natural vegetative cover accelerate the rate at which soil erodes. When these accelerated soil erosion rates continue unabated for a long period of time, the soil production potential for food and fiber can be impaired. Fresh water can be damaged by the deposition of sediments and chemicals dissolved in the runoff water.

For many years the Universal Soil Loss Equation (USLE) has been the tool of choice for sheet and rill erosion prediction and conservation planning (Wischmeier and Smith, 1978). The USLE is an empirically based model that grew from the analysis of data collected over thousands of plot-years from 1949s to 1970s. The empirical relationships are implemented through the use of tables, figures, and monographs. The model has been documented and adapted for specific uses. The form of the model is

$$A = RKLSCP$$

where

A	is the predicted average annual soil loss in tons per acre per year
R	is measured rainfall erosivity, an index combining rainfall amount and intensity
K	is the soil erodibility factor, accounting for soil characteristics including texture, organic matter content, and permeability
L	is the slope length factor
S	is the slope steepness factor
C	is the erosion reduction effect of management
P	is the erosion control practice effect

A wind erosion prediction equation developed by Woodruff and Siddowey (1965) was expressed as:

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

where

E	is predicted average annual soil loss in tons per acre per year
I	is soil erodibility index
K	is the ridge roughness factor
C	is the climatic factor
L	is the unsheltered length of eroding field factor
V	is the vegetative cover factor

The USLE and WEQ have been widely used in nationwide surveys as part of the National Resource Inventory (NRI), to express the erosion problem in term of total gross erosion per year. However, gross erosion is not a complete indicator of the extent of erosion damage. Gross erosion does not tell whether these rates are tolerable from productivity or environmental standpoint. Wischmeier and Smith, (1978) defined soil tolerance loss (T-value) as "The maximum rate of annual erosion that may occur and still permit a high level of crop productivity to be maintained economically and indefinitely". Most T-values are estimated to be within the range of 2 to 5 tons per acre per year.

The use of USLE revealed significant weaknesses. First, USLE does not fully represent all the relationships among the variables that constitute the complex process of the soil erosion, and the current form does not include all the relevant variables (Elliot et al., 1990). Second, USLE predicts gross erosion rather than net soil loss or the total eroded soil that ends up in the water ways (Crosson and Stout, 1983).

In the mid-to late 1980s the Agricultural Research Service of the U.S. Department of Agriculture (USDA-ARS) developed an improved USLE based model incorporating new data, new approaches, and corrections for USLE errors. In addition, the new technology was to be computer based replacing the tables, figures, and tedious calculations with keyboard entries. The technologies have been changed several times. A version of the software was available from the Soil and Water Conservation Society (SWCS) as RUSLE 1.04. RUSLE's specific improvements over the USLE fit into three categories. First, RUSLE incorporates more data than did the USLE from different locations, for different crops and cropping systems, for forest and rangeland erosion, and erosivity measurements. Next, RUSLE corrects errors in the USLE analysis, and fills gaps in the original data. The most significant RUSLE improvement is its increased flexibility, which allows modeling a great variety of systems and alternatives. RUSLE shows the correct trends in erosion rates for even minor changes in management practices. This increases its usefulness as a conservation-planning tool for new tillage management systems, new rotations, specialty crops, rangeland, and disturbed forest. These improvements are detailed in Renard et al. (1994). A new version of software RUSLE 2 was released in 1996 that corrects some of the deficiencies of RUSLE 1.04.

Soil Erosion Impact on productivity

Research has long established that erosion reduces crop yields. However, physical criteria such as soil loss that was an earlier measure of erosion may be misleading. The reason is some areas with high erosion rates may not suffer reduced yields if sub-soils are deep and suitable for cultivation. Damage from soil erosion is generally divided into onsite productivity impacts and offsite environmental effects. There are four concepts involved in the assessment of erosion damage: (1) a basic comparison of yields with and without conservation (or with or without erosion), (2) an awareness that yield penalty from using conservation tillage should not confound the assessment of erosion damage, (3) the identification of residual and reparable yield damage, and (4) the need to separate the effect of technical change from those of erosion (Walker, 1983). The basic idea underlying the measurement of erosion damage is the "with and without" comparison so common in economic analysis. In this measurement process two bases for comparison may be used. The first basis could be yield after zero erosion, i.e., with unchanged topsoil depth. Erosion damage in this case is the loss of yield from gross erosion associated with conventional practices. Alternatively, the basis for comparison could be yield with conservation practices versus yield without conservation practices. Here the basis for comparison is dynamic or changing over time. Erosion damage is the lost yield from the additional erosion under the conventional (erosive) system compared to conservation system. There are instances when each basis may be more appropriate than the other. The measure derived from the zero erosion basis may be more useful for evaluating alternative conservation practices in a region, while that derived from the dynamic basis would be more useful for selecting target areas for conservation emphasis.

The assessment of erosion damage should avoid confounding tillage yield penalty and erosion damage. Even with a dynamic basis for comparison, one yield-topsoil depth response function must be used to measure yield at both the conserved and eroded topsoil depth. The reason is that the conservation system may often yield slightly less at the same topsoil depth than the conventional system, meaning that its response function lies below that for the conventional system. In this case, using both functions would underestimate the damage attributable to erosion and confound it with the tillage yield penalty.

It is useful to partition yield decline from soil erosion into two components, reparable damage and residual damage. Reparable damage is usually associated with loss of soil fertility from erosion and is that portion of the yield decline from erosion that can be restored by increasing organic matter, fertilizer, or other inputs. After optimal input adjustment, there will usually be residual yield damage due to deterioration in the soil environment. Reduced moisture infiltration and retention capacity cause residual damage to yields that cannot be remedied economically.

Erosion damage assessment is considerably complicated by the impact of technical progress on yields. Yield variations over time are confounded by the joint influence of erosion that reduces yield and technology that increases it. When the effect of technical progress dominates, failure to disaggregate this joint influence could lead to an erroneous conclusion that erosion damage does not exist. Two situations could be distinguished, first the rate of technical progress is independent of the rate of erosion, and second technology is induced by erosion as explained below.

Disaggregating the joint effect of technology and erosion damage when technology is exogenous depends on whether the assessment deals with land-neutral, land-complementary, or land-substituting technology. According to Walker and Young (1986), for land-neutral technical progress, illustrated in Figure 1a, technology shifts the yield function upward from Y_0 to Y_n, increasing yield by an equal absolute amount at each topsoil depth (G'F'=G F). Without technology, soil depth is reduced from 18 to 5.2 inches with Y_0 as the production function. With technology, soil depth is reduced only to 15.4 inches and Y_n is the relevant function. In the absence of technology, yield would have declined from G to C as a result of erosion. Because technology boosts yield from G to C' in spite of erosion, one might conclude that technology has eliminated erosion. However, the correct measure of erosion damage should be based on the function Y_n, that is the decline from G' to C'. Land –neutral technical progress is most likely on cropland with deep subsoils.

Figure 1. Erosion Damage by Type of Technological Progress

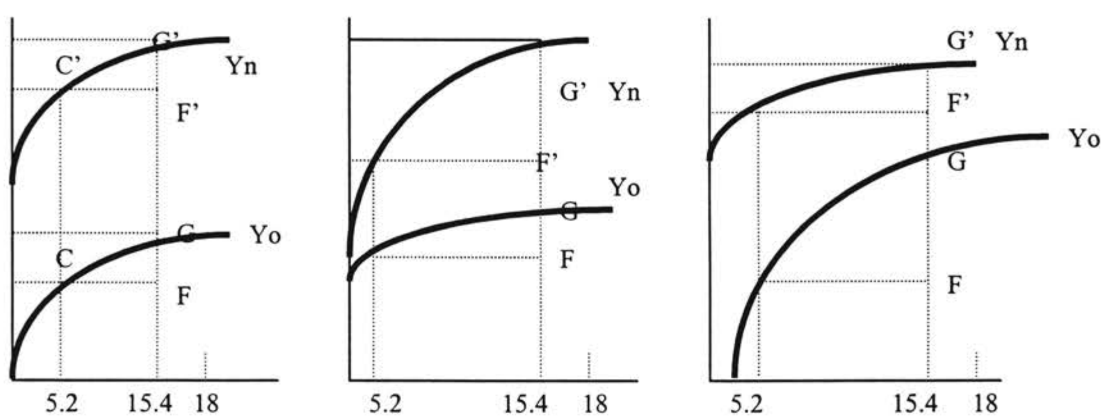


Figure 1a
Land-Neutral

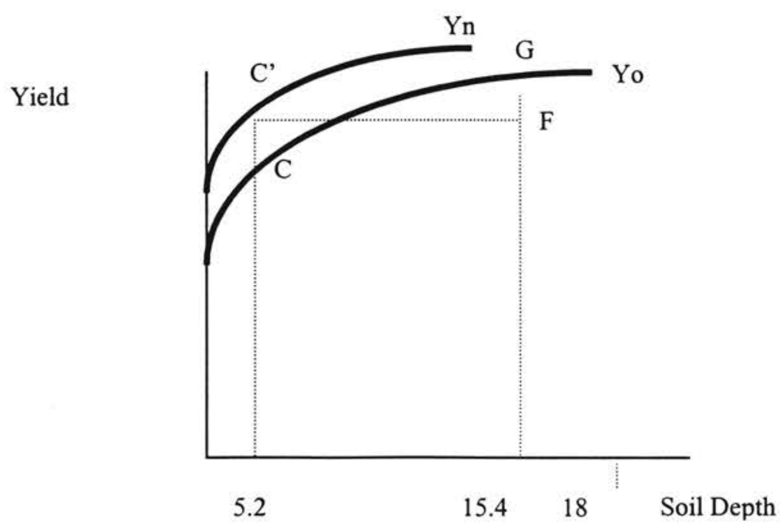
Figure 1b
Land-Complementary

Figure 1c
Land-Substituting

An example of land-complementary technical progress is where improved crop cultivars increase the yield more at deeper topsoil depths as illustrated in Figure 1b. Because land- complementary technical progress increases the slope of Y_n relative to Y_0, the appropriate measure of erosion damage (lost potential yield) G' F' is greater than the erosion damage which would be measured if technology was ignored. Land- substituting technology as in the case of tillage improvement that conserves soil moisture, boots yield at shallower top soil depth. This example is illustrated in Figure 1c. Compared with no technology, yield damage decreases (G'F'<GF)

The damage assessment outlined above is altered when the technology is induced, that is when the technical advance depends on farmer's decisions about conservation and the resulting rate of erosion. In this case, yield damage is not measured along a single technology augmented yield function Yn, but on both functions. As illustrated in Figure 2, yield damage is the difference between yield at G, conserved top-soil and unchanged technology, versus yield at C', eroded soil and induced technology. In the absence of technology, yield damage would have been the difference in yield between G and C.

Figure 2. Erosion Damage with Induced Technology



In summary, ignoring technical progress will result in unbiased damage estimates only with land-neutral technology. Ignoring land complementary technology will underestimate erosion damage, and ignoring land-substituting technical progress will overestimate erosion damage. This study will assume that the improvement in tillage intervenes in a context of land-complementary technological progress. Thus, it is expected as more soil is depleted through erosion, that the difference in yield between conventional and conservation tillage becomes wider.

Conservation Tillage

According to Unger et al. (1977) wind and water erosion are dominant problems on 19.4 million and 34.1 million acres, respectively, in the Southern Great Plains (Kansas, New Mexico, Oklahoma, and Texas). Of these 53.5 million acres, 37.2 million acres need treatment for erosion control. Conservation agencies have long promoted plant cover and residues for erosion control. Too often however, crop residues are burned or plowed under, leaving the land unprotected. Other practices that help control erosion are terracing, contour farming, and strip cropping.

Unger et al. (1977) indicate that farmer acceptance of minimum and no-tillage system has been slow. Some minimum and no-tillage system used by farmers are grain sorghum or soybeans after wheat, forage sorghums or corn after graze-out, wheat or rye continuous corn and wheat after corn silage. The most widely accepted form of conservation tillage in the Southern Great Plains is stubble mulching in wheat production, which effectively controls erosion if surface residues are adequate. An additional benefit of stubble-mulch tillage compared to conventional tillage is greater soil moisture accumulation. Thus, erosion control research has been directed toward the development of improved residue management practices for moisture storage, weed control, and crop production. In Texas, research indicates that stubble mulch increased moisture by 0.78 inch by year over that obtained by one-way tillage (Johnson and Unger, 1976). In Kansas, tillage methods ranging from conventional to near-zero tillage failed to increase soil moisture consistently in wheat-sorghum fallow rotation. This was because the residue production by the dry land crops was not adequate to increase the moisture storage efficiency (Phillips, Unger and Greer, 1976). In Oklahoma, clean tillage, stubble mulch, and combination stubble mulch and herbicide, and no-tillage with herbicide were the treatments tested in a wheat fallow rotation. Soil moisture at planting tended to be higher with stubble mulching and no-till methods than with clean tillage. Despite the equal or higher soil moisture, average wheat yields were less with stubble mulching and no-till with herbicide than with clean tillage (Phillips, Unger and Greer, 1976).

The adopter of conservation tillage must consider herbicide use, the presence of insect and plant disease, and soil characteristics. In areas where soil moisture limits crop production as in the Southern Great Plains, weed control during fallow or in crops must be nearly perfect or yields will be low. Adequate weed control is difficult to achieve with herbicide alone. This has slowed acceptance of no-tillage systems. In central Kansas, weed control with atrazine in the 11 months from wheat harvest to sorghum planting resulted in higher grain yield than sweep tillage. However, after several years, grassy weeds became a problem (Phillips, 1969).

Plant residues often harbor insects. In Texas, sweep tillage, disking or chiseling nearly eliminated southwestern corn borer larvae (Daniels and Chesdester, 1974). The larvae which normally spent winter in undisturbed corn stubble, died when tillage disturbed the soil.

Reducing or eliminating tillage has shown no consistent effect on soil's physical and chemical characteristics. In a three-year continuous wheat experiment in Oklahoma, various limited and no-tillage systems did not affect organic matter content or the bulk density of surface soil (Davidson and Santelman, 1973).

The fundamental problem facing the adoption of conservation tillage is economics. To gain widespread acceptance, conservation practices must provide economic returns equal to or greater than conventional practices. In the past, herbicides were expensive relative to labor, fuel, and machinery. This provides little incentive for switching to reduced or no tillage systems, especially since yields seldom increased. Studies by Johnson and Unger, Phillips and Unger, Unger and Parker, and Musick and Wiese have shown that some systems have increased yields over those obtained by conventional tillage. These systems include stubble-mulch tillage, reduced or no-tillage grain sorghum after wheat and fallow, and grain sorghum double-cropped after wheat. According to Unger et al. 1977, in these studies, herbicides, (usually atrazine at 3 pounds per acre and 2,4-D at 1 pound per acre) costing about $10.00 per acre replaced three to seven tillage operations. While tillage costs vary with size and type of equipment, the average is about $2.00 per acre per operation, about the same as the herbicide. This short term cost analysis does not include the soil and water conservation value of reduced or no-tillage systems, which may become more important than the immediate cash values of crop produced.

CHAPTER III

CONCEPTUAL FRAMEWORK

Economists use several models to solve problems related to economic growth and resource allocation. Before discussing the model used to solve the economic problems stated in this study we would briefly introduce theoretical models in the field of dynamic programming and optimal control theory. The discussion would extend to principles and applications of these models to areas including natural resource use and soil conservation.

Dynamic Programming Models

Dynamic Programming is a mathematical technique in which a multistage problem is broken up into a series of single stage problems. At each stage the scope of the problem is expanded a stage at a time until a simultaneous solution is obtained for the entire problem objective. 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 decisions" Bellman (1957).

A dynamic programming model could be written as:

$$\text{Max J} = \sum_{t=1}^{T-1} u(S_t, X_t) + F(S_T, X_T) \qquad (1)$$

Subject to: $S_{t+1} = f(S_t, X_t)$

$S_{(1)} =$ given initial state

where :

J	is the objective function value
$u(S_T, X_T)$	is the profit function at time t, T
$F(S_T, T)$	is the value of the terminal state at time T
X_t	is a sequence of control variable
S_t	is the state variable at time t, and
$F(S_t, X_t)$	is a state transformation function

Applying the principle of optimality the optimization problem can be written as:

$$J^*(S_t, t) == Max\lfloor u(S_t, X_t) + J^*(S_{t+1}, t=1)\rfloor \qquad (2)$$

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 equation (1), equation (2) can be rewritten as:

$$J^*(S_t, t) = Max\lfloor u(S_t, X_t) + J^*(S_{t+1}, t)\rfloor \qquad (3)$$

$$Subject\ to\ J^*(S_T, T) = F(S_T, T) \qquad (4)$$

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. Working backwards from the terminal time T to T-1, T-2 T-3…1, using equation (3), can solve the dynamic programming problem.

Optimal Control Theory

The maximum principle described above is also applied in optimal control theory models. Optimal control theory is generally formulated in a continuous time frame. However, both discrete and continuous time models will be presented.

Discrete time model

Consider the following model

$$\text{Maximize } W= \quad \sum_{t=1}^{T-1} u(S_t, X_t) + F(S_t, T) \qquad (5)$$

$$\text{Subject to} \quad S_{t=1} - S_t = f(S_t, X_t) \qquad (6)$$

$$\text{and} \quad S_{(1)} = a \qquad (7)$$

where W is the objective function value and a is the initial value of the state variable. Equation (6) is a difference equation which describes the change of the state variable determined by the function $f(s_t,x_t)$. All the other variables are as described above.

The Lagrangian function can be written as:

$$L = \sum_{t=1}^{T-1} u(S_t, X_t) + \sum_{t=1}^{T-1} \lambda_t (S_t - S_{t+1} + f(\bullet)) + F(S_T, T) \qquad (8)$$

where λ_t is the Lagrangian multiplier. The first order necessary conditions for maximum are:

1. $$\frac{\partial L}{\partial X_t} = \frac{\partial u(\bullet)}{\partial X_t} + \lambda_t \frac{\partial f(\bullet)}{\partial X_t} = 0 \qquad (10)$$

2. $$\frac{\partial L}{\partial S_t} = \frac{\partial u(\bullet)}{\partial S_t} - \lambda_{t-1} + \lambda_t \left(1 + \frac{\partial f(\bullet)}{\partial S_t}\right) = 0 \qquad (11)$$

3. $$\frac{\partial L}{\partial \lambda_t} = S_t - S_{t-1} + f(\bullet) = 0 \qquad (12)$$

4. $$\frac{\partial L}{\partial S_T} = -\lambda_T + \frac{\partial F(\bullet)}{\partial S_T} = 0 \qquad (13)$$

Equations (10) through (13) can be rewritten as

1. $$\frac{\partial u(\bullet)}{\partial (X_t} + \lambda_t \frac{\partial f(\bullet)}{\partial X_t} = 0 \qquad (14)$$

2. $$\lambda_t - \lambda_{t-1} = -\left(\frac{\partial u(\bullet)}{\partial S_t} + \lambda_t \frac{\partial f(\bullet)}{\partial S_t}\right) \qquad (15)$$

3. $$S_{t-1} - S_t = f(\bullet) \qquad (16)$$

4. $$\lambda_T = \frac{\partial F(\bullet)}{\partial S_T} = 0 \qquad (17)$$

5. $$S_{(1)} = a \qquad (18)$$

Equations (14) through (18) are known as "maximum principal" in a discrete –time context.

Continuous time model

The continuous time model is formulated as:

Maximize $W = \int_0^T u\big(S(t), X(t), t\big)dt + F\big(S(T), T\big)$

Subject to: $\frac{dS}{dt} = \dot{S} = f\big(S(t), X(t)\big)$

and $S(0) = a$

The Hamiltonian function is defined as:

$$H\big(S(t), X(t)\big) = u\big(S(t),\ X(t),\ t\big) + \lambda(t) f\big(S(t), X(t)\big)$$

where λ_t is called the co-state variable. This function is equal to the profit plus the change in the stock valued by its shadow price. The Hamiltonian allows a convenient representation of the necessary conditions, which comprise the maximum principle[1]. The necessary conditions of the continuous time model are obtained by taking the partial derivatives of the Hamiltonian function with respect to the state variable, the control variable and the co-state variable, and setting them equal to zero. The necessary conditions are:

1. $$\frac{\partial H}{\partial X_t} = 0 \qquad (14')$$

2. $$\frac{d\lambda}{dt} \equiv \dot{\lambda} = -\frac{\partial H}{\partial S_t} \qquad (15')$$

3. $$\frac{dS}{dt} \equiv \dot{S} = f\big((S(t), X(t)\big) \qquad (16')$$

4. $$\lambda(T) = \frac{\partial F}{\partial S(T)} \qquad (17')$$

5. $$S(0) = a \qquad (18')$$

Condition (14') is the maximum condition, conditions (15') and (16') are the joint equations, condition (17') is the transversality condition, and (18') is the initial value of the state variable. There are three main attributes to the transversality condition; the first

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[1] For detailed discussion of the maximum principle see Bryson and Chiho (1975), Conrad and Clark (1987) or Intrilligator (1971)

specifies the constraints on the state variable, the second is whether time is fixed or free, and the third concerns the presence of 'scrap-value' function, which places a value on the stock at the terminal time. The first constraint is that the value of the co-state at the end of the planning horizon is zero either with a fixed or infinite time horizon. The second attribute requires that the constraint upon the resource be a weak inequality ($x(T) \geq x_T$), that is the stock equals the constraint x_T. The third attribute requires that, where the scrap value exists, the co-state value equals the marginal scrap value.

For a non-renewable resource problem, the terminal time is where:

$$u(X(T), S(T), T) = \lambda(T)q(T),$$

that is, the profit in the last period equals the marginal value of the stock extracted. In other words, the Hamiltonian at the terminal time equals zero.

Model of Natural Resource Use

The following discussion is an application of the maximum principle in discrete time framework and of the optimum control theory in a continuous time framework, to resource use. The problem concerns a mine owner who has a stock of a given natural resource, S_t in time t. The extraction cost represented by $c(q_t, s_t)$, is a function of the quantity extracted, q_t, in time t and the remaining stock, with the assumption that cost is positively related to quantity extracted ($\partial c/\partial q > 0$), and negatively related to stock available ($\partial c/\partial s < 0$). Assuming a constant price p, and discount rate r, the problem of the mine owner is maximizing the present value of the stream of net benefits given the constraint that only the available resource can be extracted.

Discrete Model

In the discrete time framework, the problem can be presented as:

$$\text{Maximize NB} = \sum_{t=1}^{T} \frac{pq_t - c(q_t, s_t)}{(1+r)^t} \quad (19)$$

$$\text{Subject to: } s_{t+1} = s_t - q_t, \; t = 1, \ldots\ldots T-1 \quad (20)$$

$$s(1) = a \quad (21)$$

$$s_T = \bar{s}_T \quad (22)$$

The Lagrangian function is

$$L = \sum_{t=1}^{T} \frac{pq_t - c(q_t, s_t)}{(1+r)^t} + \sum_{t=1}^{T-1} \alpha_t (s_t - s_{t+1} - q_t) + \beta_t (\bar{s}_T - s_T) \quad (23)$$

where α_t and β_t are the Lagrangian multipliers. Differentiating the Lagrangian function with respect to q_t, s_t, and α_t and equating the derivatives to zero derives the necessary conditions for maximum. The necessary conditions are:

1. $$\frac{\partial L}{\partial q_t} = \frac{p - \partial c / \partial q_t}{(1+r)^t} - \alpha_t = 0,\; t = 1, \ldots\ldots, T \;\; or\; p = \frac{\partial c}{\partial q_t} + \alpha_t (1+r)^t \quad (24)$$

2. $$\frac{\partial L}{\partial s_t} = \frac{\partial c / \partial s_t}{(1+r)^t} + \alpha_t - \alpha_{t-1} = 0,\; t = 1, \ldots., T \quad (25)$$

3. $$\frac{\partial L}{\partial \alpha_t} = s_t - s_{t-1} - q_t \; t = 1, \ldots\ldots, T \quad (26)$$

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 at time t+1. Alternatively 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 time t+1. The Lagrangian multiplier is referred to as the user cost or "shadow price".

Equation (24) states that extraction should continue until the price of the resource should equal the marginal cost of extraction, plus the discounted value of the user cost α. Consider equation (25) and replacing α_t by $\lambda_t(1+r)^{-t}$, where λ_t is the undiscounted Lagrangian multiplier yields:

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

$$\text{or } \frac{(\lambda_t - \lambda_{t-1})}{\lambda_{t-1}} = r + \frac{\partial c}{\partial s_t \lambda_{t-1}} \qquad (27)$$

Equation (27) indicates that the rate of change of the user cost depends on the discount rate and the effect of the remaining stock on the extraction cost. If the remaining stock has no effect on the cost (i.e. $\partial c / \partial s_t = 0$), then the user cost should increase at the rate of the discount. If $\partial c / \partial s_t < 0$, then the undiscounted user cost must increase less than the discount rate. In this case the rate of resource depletion will be lower than when there is no stock effect on the cost of extraction.

Continuous Time framework

The optimal resource use problem with continuous time periods can be stated as:

$$\text{Maximize NB} = \int_0^T [pq_t - c(q_t, s_t)]e^{-rt} dt \qquad (19')$$

$$\text{Subject to: } \dot{s} = \frac{ds_t}{d_t} = -q_t \qquad (20')$$

$$s(1) = a \qquad (21')$$

$$s_T = \bar{s}_T \qquad (22')$$

The undiscounted Hamiltonian function is given by:

$$H = pq_t = c(q_t, s_t) - \lambda_t q_t \tag{23'}$$

where q_t is the control variable, s_t is the state variable, and λ_t is the co-state variable. Differentiating the Hamiltonian function with respect to q_t, s_t and λ_t allows solving the problem defined in equations (28) through (31), according to the maximum principle of the optimum control theory. The first order conditions are as follow:

1. $$\frac{\partial H}{\partial q_t} = pq_t - \frac{\partial c}{\partial q_t} - \lambda_t = 0 \tag{24'}$$

$$-\frac{\partial H}{\partial s_t} = \dot{\lambda} \equiv \frac{d\lambda_t}{dt} \tag{25'}$$

$$\frac{\partial H}{\partial \lambda_t} = 0 \;\; or \;\; \dot{s} - q_t = 0 \tag{26'}$$

Assume $\tilde{H}$ is a discounted Hamiltonian, then we have:

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

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

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

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

By substituting $\dot{\alpha}$ where $\dot{\alpha} = -\frac{\partial \tilde{H}}{\partial s_t}$, (analogous to condition (25') we obtain:

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

Then recognizing that $\frac{\partial \tilde{H}}{\partial s_t} = -e^{rt}\frac{\partial c}{\partial s_t}$ and substituting it, we obtain:

$$\dot{\lambda} = r\lambda_t + \frac{\partial c}{\partial s_t} \qquad (27')$$

Conditions (24') through (27') of the continuous time model are equivalent to conditions (24) through (27) of the discrete time model, respectively. Condition (24') states that the optimal resource extraction is obtained where the net benefit from a marginal unit extracted is equal to the user cost at each time period. Condition (25') requires that the rate of extraction satisfy the equation of motion (20'). Condition (27') states that the user cost of a unit of resource stock should increase at the discount rate plus the effect of the depletion on the cost of extraction.

Discrete Economic Model of Soil Conservation

The central question in formulating an economic model for soil conservation is to find whether the benefits derived from conservation practices provide enough incentive for farmers to adopt those practices. That is whether the discounted benefits more than offset the discounted costs. Because in many circumstances farmers face discrete decision choices, the discounted benefits and costs are analyzed using discrete time model.

Assume the producer has a single commodity with a production function expressed as $y(x_t, d_t)$, where x_t is a vector of inputs such as labor, fertilizer, pesticides, and machinery used in period t, and d_t is the stock of soil available in period t. Assume the first derivative of the yield function with respect to x_t, and d_t is positive. Assume also that the producer has a cost function $c(x_t, d_t)$. The problem facing the producer is to maximize the net present value of returns (V) from a single soil resource over the planning horizon subject to changes in soil depth determined by the equation of motion. The model is presented as follow:

$$\text{Maximize } V = \sum_{t=1}^{T-1}\left[\frac{P\,y(x_t,d_t) - c(x_t,d_t)}{(1+r)^t}\right] + \frac{F(d_T)}{(1+r)^T} \tag{28}$$

$$\text{Subject to } d_{t+1} = d_t + f_t(x_t) \tag{29}$$

$$d(1) = \bar{d} \tag{30}$$

$$x_t \geq 0,\ d_t > 0 \tag{31}$$

where P is the price of output , $f_t(x_t)$ is the function that determines the rate of change of soil depth which is a function of the input used, T is the length of the planning horizon, r is the private discount rate, and F is the value of the land at the end of the planning period, which is a function of the remaining soil depth at time T. The state variable is soil depth d_t, and the control variable is the bundle of inputs used, x_t.

The Lagrangian function is determined as:

$$L = \sum_{t=1}^{T-1}\left[\frac{P\,y(x_t,d_t) - c(x_t,d_t)}{(1+r)^t}\right] + \sum_{t=1}^{T-1}\alpha_t(d_t - d_{t+1} - f_t(x_t)) + \frac{F(d_T)}{(1+r)^T} \tag{32}$$

The necessary conditions are:

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

$$\text{or } P\frac{\partial y}{\partial x_t}\frac{1}{(1+r)^t} = \frac{\partial c}{\partial x_t}\frac{1}{(1+r)^t} + \alpha_t\frac{\partial f_t}{\partial x_t} \tag{33}$$

2. $$\frac{\partial L}{\partial d_t} = \frac{P\frac{\partial y}{\partial d_t} - \frac{\partial c}{\partial d_t}}{(1+r)^t} + \alpha_t - \alpha_{t-1} = 0 \tag{34}$$

Substitute $\alpha_t = \lambda_t (1+r)^{-t}$ in equation (34)

$$\frac{(\lambda_t - \lambda_{t-1})}{\lambda_{t-1}} = r - \frac{1}{\lambda_{t-1}}\left(\frac{P\partial y}{\partial d_t} - \frac{\partial c}{\partial d_t}\right) \tag{35}$$

3. $$\frac{\partial L}{\partial \alpha_t} = 0 \rightarrow d_{t+1} - d_t = f_t(x_t) \tag{36}$$

4. $$d(1) = \bar{d} \tag{37}$$

5. $$\frac{\partial L}{\partial x_t} = -\alpha_t + \frac{\partial F}{\partial x_T} = 0 \rightarrow \alpha_T = \frac{\partial F}{\partial x_T} \tag{38}$$

The necessary conditions for optimal input use are described by equations (33) through (38). Equation (33) states that input should be used in production until the present value of the value marginal product is equal to the present value of 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 has no impact on future soil depth and residual nitrogen, then these equations become the classical static marginal or first order conditions. That is, optimal input use is where the value of the marginal product is equal to the marginal factor cost.

The Lagrangian multipliers α_t measures how much the maximum value of the objective function would increase per unit increase in soil depth. In other words, α_t measures the decline in the optimal value of the objective function from the loss of a marginal unit of soil depth. It is the forgone future profit or user cost per unit of soil eroded in the current period. Equation (34) and equation (35) show the behavior of the (undiscounted) marginal user costs. The conditions require that the marginal user cost should grow at the rate of discount less the soil's contribution to current profit. Equation (36) is a restatement of the difference equation for the soil depth, and equation (37) sets the initial conditions of the soil depth. Equation (38) defines the terminal value of the user cost (α_t).

Basic model of the Study

Private optimization

The problem of selecting the optimal tillage system and nitrogen level by a private producer to reduce soil erosion may be approached using the theory developed in the soil conservation model described above. The producer may be considered as making an investment decision to improve the long-term productivity of his land. The adoption of conservation practices depends on net returns and associated risks. Investment costs consisting of the costs of conservation tillage systems, weed control, and nitrogen application are incurred with the expectation that reduced soil erosion will increase land productivity and future profit. Assuming no-offsite damage costs, farmers will choose to protect against any productivity loss due to erosion if the discounted expected returns are greater than the discounted costs.

Assume that the productivity of land is a function of topsoil depth, the level of nitrogen, and the type of tillage system used and is expressed as:

$$Y_t = f(D_t, TNO3_t, N_t, M_t) \qquad (39)$$

where Y_t is yield at time t, D_t is the level of topsoil depth at time t, $TNO3_t$ is the residual nitrogen at time t , N_t is applied nitrogen at time t, and M_t is the tillage system used at time t. The quantity ($TNO3_t$, N_t) represents the quantity of residual and applied inorganic nitrogen available to the crop at time t. Part of the total nitrogen is used by the crop in the production process. A residual quantity of nitrogen remains unused and may remain in the soil or subsoil, or it may leach to lakes and reservoirs, causing off-site damages.

The first derivative of the yield function with respect to D_t is expected to be positive. An increase in the stock of soil has a positive effect on output because soil holds nutrients and water vital to plant growth. We also assume nitrogen to have a positive relationship with yield. Conservation tillage systems may reduce current yield but may slow erosion so that future yields may be higher if conservation practices are used. The main impact of the tillage system on yield occurs through its impact on soil depth, which also affects the impact of nitrogen on yield. The interaction effect between soil depth and nitrogen on yield will be negative if these inputs are substitutes.

There are two state variables (soil depth and residual nitrogen) and two control variables (applied nitrogen and type of tillage system). The state variables are described by the following equations of motion:

$$D_{t+1} = D_t - f(M_{it}) \tag{40}$$

$$TNO3_{t+1} = g(D_t, TNO3_t, N_t) + \varepsilon_t \tag{41}$$

where: M_{it} is the i_{th} tillage system used at time t with $M_{it} = 1$ if tillage i is used and 0 otherwise, $f(M_{it})$ is the function that determines the rate of erosion according to the type of tillage system used, $g()$ is the function that determines the amount of residual nitrogen for the period t+1, and ε_t represents other factors which affect residual nitrogen but are not included in the function g().

Assume also that the producer has a cost function $C(D_t, M_t, N_t)$ where D_t, Mt, and Nt are as described earlier. The problem facing the farmer is to choose tillage systems and nitrogen application rates that maximize the net present value of returns from land resources over the planning period. The choice of tillage systems affects erosion rates and hence soil depth, and residual nitrogen levels, as described by the above equations of motion.

The maximization problem is presented as:

$$\underset{M,N}{Max}\, NPV = \sum_{t=1}^{T-1}\left[\frac{P\,Y(D_t, TNO3_t, N_t), - C(D_t, N_t, M_t)}{(1+r)^t}\right] + \frac{F(D_t, TNO3_T)}{(1+r)^T} \quad (42)$$

Subject to: $D_{t+1} = D_t - f(M_t)$ (43)

$$D(1) = \bar{D} \quad (44)$$

$$TNO3_{t+1} = g(D_t, TNO3_t, N_t) \quad (45)$$

$$TNO3(1) = T\bar{N}O3 \quad (46)$$

$$\sum_{i}^{n} M_{it} = 1 \quad (47)$$

$$D_t, TNO3_t, N_t, M_t > 0$$

where P is the price of output, T is the length of the planning horizon, r is the discount rate, F is the final salvage or sale value of the land at the end of the planning horizon. That is the ending salvage value at time T is assigned to be a function of the remaining soil depth and residual nitrogen. The necessary conditions for optimum can be derived from the first derivatives of the following Lagrangian function:

$$L = \sum_{t=1}^{T-1}\frac{PY(D_t, TNO3_t, N_t, M_t) - C(D_t, N_t, M_t)}{(1+r)^t} + \frac{F(D_T, TNO3_T}{(1+r)^T} + \varphi_t(1 + \sum_{i}^{n} M_{it})$$
$$+ \sum_{t=1}^{T-1}\alpha_t(D_t - D_{t+1} - f(M_t)) + \sum_{t=1}^{T-1}\beta_t(TNO3_{t+1} - g(D_t, TNO3_t, N_t)) \quad (48)$$

The necessary conditions for optimum are:

$$\frac{\partial L}{\partial N_t} = \frac{P\frac{\partial y}{\partial N_t} - \frac{\partial c}{\partial N_t}}{(1+r)^t} - \beta_t \frac{\partial g}{\partial N_t} = 0$$

$$P\frac{\partial Y}{\partial N_t}\frac{1}{(1+r)^t} = \frac{\partial C}{\partial N_t}\frac{1}{(1+r)^t} + \beta_t \frac{\partial g}{\partial N_t} \tag{49}$$

$$\frac{\partial L}{\partial M_t} = \frac{P\frac{\partial y}{\partial M_t} - \frac{\partial c}{\partial M_t}}{(1+r)^t} - \varphi_t - \alpha_t \frac{\partial f}{\partial M_t} = 0$$

$$P\frac{\partial Y}{\partial M_t}\frac{1}{(1+r)^t} = \frac{\partial C}{\partial M_t}\frac{1}{(1+r)^t} + \varphi_t + \alpha_t \frac{\partial f}{\partial M_t} \tag{50}$$

$$\frac{\partial L}{\partial TNO3_t} = \frac{P\frac{\partial Y}{\partial TNO3_t}}{(1+r)^t} + \beta_{t+1} - \beta_t \frac{\partial g}{\partial TNO3_t} = 0$$

$$P\frac{\partial Y}{\partial TNO3_t}\frac{1}{(1+r)^t} = -\beta_{t+1} + \beta_t \frac{\partial g}{\partial TNO3_t} \tag{51}$$

$$\frac{\partial L}{\partial D_t} = \frac{P\frac{\partial Y}{\partial D_t} - \frac{\partial C}{\partial D_t}}{(1+r)^t} + \alpha_t - \alpha_{t-1} - \beta_t \frac{\partial g}{\partial D_t} \tag{52}$$

Assuming that the undiscounted Lagrangian multipliers $\lambda_t = \alpha_t(1+r)^t$, and $\omega_t = \beta_t(1+r)^t$, by substituting λ_t and ω_t in equation (52), and multiplying both sides by $(1+r)^t$, this equation can be simplified to give:

$$\frac{(\lambda_t - \lambda_{t-1})}{\lambda_{t-1}} = r - \frac{1}{\lambda_{t-1}}\left(\frac{P\,\partial Y}{\partial D_t} - \frac{\partial C}{\partial D_t}\right) + \frac{\omega_t}{\lambda_{t-1}}\frac{\partial g}{\partial D_t} \tag{53}$$

The Lagrangian function is also differentiated with respect to each of the Lagrangian multipliers. These ensure the constraints are met.

$$\frac{\partial L}{\partial \alpha_t} = 0 \rightarrow D_t - D_{t-1} - f(M_t) = 0 \tag{54}$$

$$\frac{\partial L}{\partial \beta_t} = 0 \rightarrow TNO3_{t+1} - g(D_t, TNO3_t, N_t) = 0 \tag{55}$$

$$TNO3(1) = T\bar{N}O3 \tag{56}$$

$$D(1) = \bar{D} \tag{57}$$

The necessary conditions for optimal input use without taking into account off-site damages of soil erosion are described by equations (49) through (57). Equations (49) and (50) are equivalent to equation (33). These conditions state that tillage systems should be used, and nitrogen applied in production until the present value of the marginal product is equal to the present value of the marginal factor cost of the input used plus the present value of any loss in future productivity due to soil depletion or residual nitrogen loss. If the current input has no impact on future soil depth and residual nitrogen, ($\partial f/\partial M_t=0$ and $\partial g/\partial N_t=0$, respectively), then these equations become as indicated earlier the classical static marginal or first order conditions. That is, optimal input use is where the value of the marginal product is equal to the marginal factor cost.

The Lagrangian multipliers α_t and β_t measure how much the maximum value of the objective function would increase per unit increase in soil depth and residual nitrogen, respectively. In other words, α_t and β_t measure the decline in the optimal value of the objective function from the loss of a marginal unit of soil depth or residual nitrogen. They are the forgone future profit or user cost per unit of soil eroded and residual nitrogen in the current period, respectively. Equation (53) like equation (35) requires that the marginal user cost should grow at the rate of discount less the soil's contribution to current profit. Equations (54) through (57) restate the equations of motion and initial values of residual nitrogen and soil depth.

Social Optimization

The public or social analysis is derived by assuming that the farmer does take into account off-site damages. The profit function is indicated by the following equation:

$$\pi_{st} = \pi_{pt} - t_n Nloss_t(D_t, N_t, TNO3_t) - t_e f(M_t) \qquad (58)$$

where π_{st} is the present value of social net returns taking into account off-site damages, π_{pt} is the private profit as described by equation (41), t_n is the charge per unit of nitrogen loss, $Nloss_t$ is the amount of nitrogen loss at time t, t_E is the charge per unit of erosion, E_t is the amount of erosion at time t. The charges on nitrogen loss and erosion are designed to internalize the cost of soil erosion and nitrogen loss by imposing a "Pigouvian" tax. The corresponding first order conditions for maximizing π_{st} given changes in nitrogen level and tillage system are:

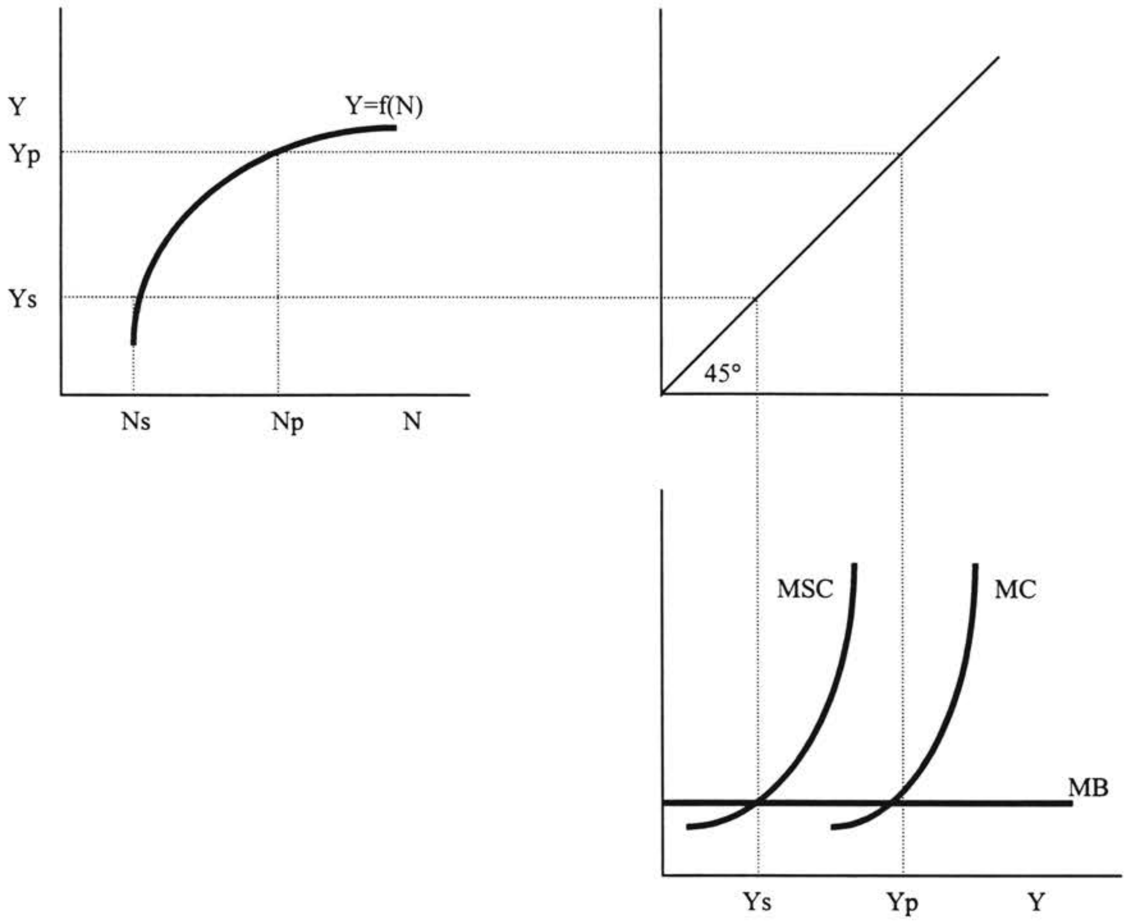
$$P\frac{\partial Y}{\partial N_t}\frac{1}{(1+r)^t} = \frac{\partial C}{\partial N_t}\frac{1}{(1+r)^t} + \beta_t\frac{\partial g}{\partial N_t} + t_n\frac{\partial Nloss_t}{\partial N_t}\frac{1}{(1+r)^t} \qquad (59)$$

$$P\frac{\partial Y}{\partial M_t}\frac{1}{(1+r)^t} = \frac{\partial C}{\partial M_t}\frac{1}{(1+r)^t} + t_n\frac{\partial Nloss_t}{\partial M_t}\frac{1}{(1+r)^t} + t_e\frac{\partial f}{\partial M_t} \qquad (60)$$

It is expected that the marginal changes of nitrogen loss and soil erosion with respect to variation in nitrogen level be positive. Thus, compared to equation (49) and equation (50), equation (59) and equation (60) show that the value of the marginal product must be increased by the sum of the marginal costs of off-site damages, for an optimal level of nitrogen and type of tillage system.

The value of the marginal product of applied nitrogen is a decreasing function of the quantity of soil erosion, and nitrogen loss, whereas the marginal factor cost is an increasing function. Therefore, if the farmer were to take into account all the costs of his production activities, it is expected that he will use less nitrogen and more conservation tillage systems to decrease soil erosion, maintain land productivity, and limit off-site damages. A graphical representation of the private and social optimal nitrogen application is shown on Figure 3. In order to make the producer internalize the marginal damage cost s associated with the off-site damages, one may is to set a tax equal to marginal off-site costs. Thus, the producer maximizes profit by setting his marginal benefit (MB) equal to the marginal social cost (MSC), which is the sum of his marginal cost (MC) and the tax representing the marginal off-site costs. As Figure 3 shows the producer will likely reduce nitrogen application. Np and Ns represent the optimum levels of nitrogen, respectively for the private and social optimum.

Figure 3. Private and Socially Optimum Levels of Applied Nitrogen



CHAPTER IV

METHOD AND PROCEDURES

Empirical Model

The main objective of the study is to determine the most profitable long-term use of tillage systems and inorganic nitrogen when there is a concern about off-site damages from soil erosion and nitrogen loss. The basic model described above examines the simple case where the farmer was operating on one soil type using one tillage system. This analysis is extended to a situation where the landscape is composed of different soil types and that one tillage system is chosen for all soil types. This objective is achieved by choosing the levels of nitrogen and type of tillage system that maximize farmers' profit in the long run subject to limitations of nitrogen losses causing off-site damages. The following model was developed for empirical solution:

$$\underset{N,M}{Max}\, NPV = \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{i=1}^{I} A_j \begin{bmatrix} P_y Y_{ijt}(D_{jt}, N_{jt}, TNO3_{jt}, M_{it}) - VC_t(N_{jt}, M_{it}) \\ -t_n Nloss_{jt} - t_e E_{ijt}) \end{bmatrix} (1+r)^t \quad (61)$$

Subject to:

$$D_{jt+1} = D_{jt} - E_{ijt}(D_{jt}, M_{it}) \quad (62)$$

$$D_{j0} = \bar{D}_{j0} \quad (63)$$

$$\sum_{i=1}^{I} M_{it} = 1 \qquad for\, all\, t \quad (64)$$

$$Nloss_{jt} = f(D_{jt}, N_{jt}, TNO3_{jt}) \quad (65)$$

$$TNO3_{jt+1} = g(D_{jt}, N_{jt}, TNO3_{jt}) \quad (66)$$

$$TNO3_{j0} = \bar{TNO3}_{j0} \quad (67)$$

$$D, M, N, TNO3 > 0$$

where

t =1,2,…,T	is the planing horizon
i= 1,2,…,I	is the number of alternative tillage systems
j =1,2,…,J	is the number of soil types on the farm
Y_{ijt}	is the yield of wheat in soil type j, using tillage i at time t, in metric ton per hectare
P_y	is the price of the product in dollars per metric ton
A_j	is the cultivated area in hectares of soil type j
D_{jt}	is the depth of soil j at time t in meters
VC_t	is the variable cost at time t in dollars per hectare
N_{jt}	is the amount of nitrogen applied to soil type j at time t in kilograms per hectare
M_{it}	is a zero-one integer variable of the type i of tillage used in time t
t_n	is the off-site cost in dollars per kg of nitrogen loss
$Nloss_{jt}$	is the amount of nitrogen loss in soil type j at time t in kilograms per hectare
t_e	is the cost in dollars per metric ton of soil lost
E_{ijt}	is the amount of erosion in metric in meters from soil type j when tillage system i is used at time t in meters

S_{jt} is the index for soil type j in the farm at time t

r is the discount rate

The objective function equation (61) is the present value of net returns per hectare above the cost of nitrogen, machinery, and off-site damages aggregated across all tillage systems and soil type of the farm for the entire planning period. The constraints are given by equations (62) through equation (67). Equation (62) is a soil depth transition equation for soil type S_j. Equation (63) sets the initial soil depth at a given level. Equation (64) ensures that no more than one tillage system is chosen for a given year. Equation (65) allows determining the amount of nitrogen lost each year per soil type from surface runoff and leaching below the soil surface. Equation (66) determines nitrogen carryover.

Objective four of the study will be achieved by comparing the feasibility of obtaining meaningful solutions by the GAMS-MINOS, and by the EXCEL non-linear problem solver.

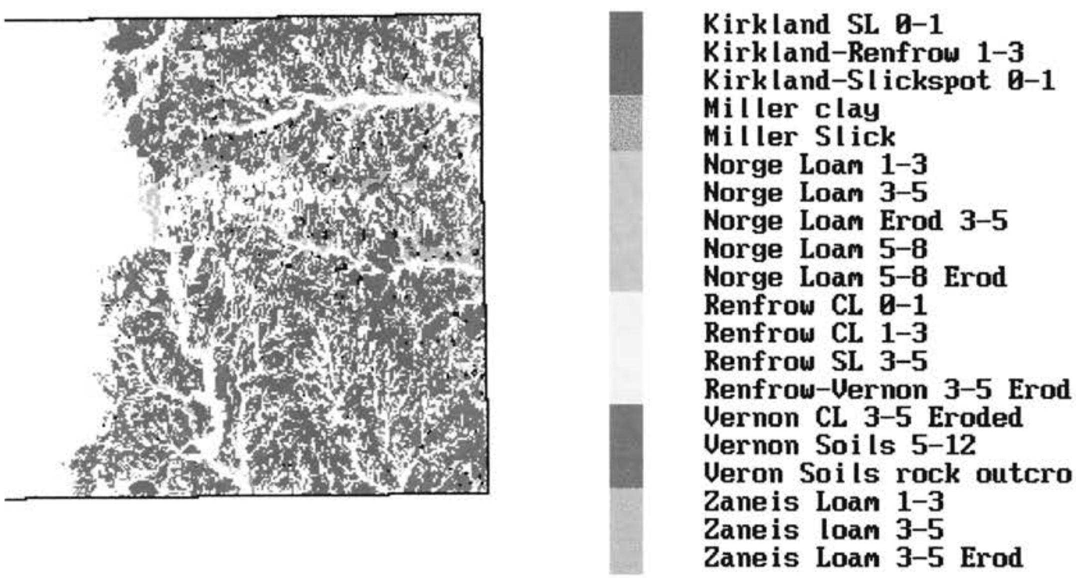
The proposed problem is of discrete non-linear form. The size and complexity of the problem increases rapidly with the length of the planning horizon and the number of non-linear constraints. Computational difficulties are anticipated and the method by which these difficulties are solved will be useful for further research.

Study Area

The study area was Garfield County Oklahoma where despite a high yield potential, 17% of the cropland is classified as highly erodible with an erodibility index greater than 8 according to the 1982 National Resources Inventory (NRI). This means that the soil could potentially erode more than 8 times the rate at which it is renewed.

However, the rate of erosion varies according to soil type. The main factor affecting soil erosion is its slope. Farming is assumed to take place in a pattern of soil in the Renfrow-Vernon-Kirland association shown on the map below. This association includes three

Study Area: Renfrow-Vernon-Kirkland Association in Garfield County, Oklahoma



other soil types (Norge, Miller, and Zaneis). The association consists of deep and shallow soils, nearly level to gently sloping upland, and moderately well drained. Kirland constitutes 53% of the area, followed by Vernon 21% and Renfrow 19%. Norge, Miller and Zaneis account for 7% of the area.

Four tillage systems were selected for this study. They were (i) Plow, (ii) Disk Chisel, (iii) Sweep Once, and (iv)Sweep Twice. The following is a summary description of these systems as indicated by Epplin et al.

The Plow system, which is a conventional tillage system, consists of a disk operation immediately after the harvest. The land is then tilled with a moldboard plow. A second disk operation is assumed to follow in August. A field cultivator is used to apply fertilizer. The Disk Chisel system consists of a disk operation after harvest, followed by one chisel operation in July and another in August. Fertilizer is applied in late August with a field cultivator. The Sweep Twice system includes 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 are used with a second tillage operation. Anhydrous ammonia is also applied with the same operation. The Sweep once system consists of only one V-blade sweep operation combined with anhydrous ammonia. Post harvest herbicides of Bladex and Atrazine are applied.

Data Requirements

Data needs included crop enterprise budgets for the tillage systems used, estimates of wheat yield as a function of fertilizer and soil depth, nitrogen loss, and amount of erosion by soil type and tillage system. The Oklahoma State University Enterprise Budget generator was used to estimate a budget for each of the four tillage systems. Variable costs include the costs of wheat seed, phosphorus, harvesting, pesticide, annual operating capital, machinery labor, fuel and repairs. The cost of phosphorus was separately estimated on the assumption that EPIC used 46 kg of P2O5 per hectare. The consumer price index was 107 and 115 in 1996 and 1999, respectively. Using this index, the price of P2O5 representing 45% of the price of ($266/MT), was estimated at $0.72 per kg. The corresponding cost of phosphorus was $33.12 per hectare.

Each tillage system has fixed machinery investment costs, which must be paid when a given system is used. Machinery ownership costs are the sum of depreciation, interest, and taxes. The budget summaries are shown in Table 1. Detailed budgets are contained in Appendix Table 20. They indicate that the annual variable costs were greatest for the SWP2 and SWP1 because the cost of greater use of herbicide for effective weed control more than offsets the lower costs for fuel repair and labor. However, these systems require lower machinery cost than PL and DC system. The PL system requires the greatest machinery investment. Total production costs for the SWP2 and SWP1 systems are greater than the total production cost of DC system. The total cost of the PL system is the highest. The DC system has the lowest total cost but a higher erosion rate than the sweep systems although lower than the plow system. The question is whether the higher current returns from conventional systems will be offset by both reduced long-term soil erosion cost, and optimum use of nitrogen to limit off-site damages, which will allow farmers to choose sweep systems.

The study assumes a base line wheat price of $110 per metric ton, while the price of nitrogen is $0.55 per kilogram.

Table 1. Cost of Production for Wheat for Alternative Tillage Systems

Type of Cost	Disk Chisel	Plow	Sweep Twice	Sweep Once
Operating Costs ($/ka)	138.2	142.58	197.27	174.34
Fixed Costs ($) , 243 Ha	84864	157346	67231	67231

Source: OSU Enterprise Budget

Data required for estimating the functions of crop yield, nitrogen loss, and level of erosion nitrogen loss per tillage system and soil type, are not available. They can be only obtained through simulation models. Thus, data were obtained by simulation using the

Erosion Productivity Impact calculator or EPIC Model (William et al., 1983). Input data required by the EPIC model includes soil profile characteristics, topographic factors (slope and slope-length), weather (temperature, rainfall, and wind), and crop management data (tillage systems, crop, inputs). The model generates daily stochastic wheat yield, nitrogen loss, and soil erosion rates for each tillage system for a given soil type and level of applied nitrogen. Thus, the functions used by EPIC are too complicated and cumbersome for an optimization program. In order to simplify the functions of yield, nitrogen loss, and residual nitrogen, the model was used to generate replicated relevant variables for regression analysis.

The experiment conducted for this study in generating the required data for the regression analysis consisted of simulating over a 1 00 year-period, four different levels of nitrogen application (16, 50, 100, and 150) kg per hectare for each of the four tillage systems and six soil types. Thus, 1600 observations were generated for each soil type.

Estimation Methods

Statistical Model

The optimization problem concerned in this study requires input-output relationships along with equations representing soil depth transition, nitrogen carryover, and nitrogen loss per soil type and tillage system. These relationships were determined through regression analysis using 9600 observations of simulation data. The statistical estimation was made by considering each treatment or level of fertilizer application over a 100 year-period as one of 96 cross sectional units (4 fertilizer levels X 4 tillage systems

X 6 soil types). Data from the four treatments for each soil type were pooled and arranged so that all observations appear together by tillage system within soil type. It is assumed that tillage system and treatment (applied nitrogen) have fixed effects. There are 100 replications corresponding to 100 years of simulation which have a random effect assumed to be normally distributed with zero mean and variance $\sigma_t 2$.

The statistical model for each soil type can be represented as:

$$Y_{ikt} = \mu + \alpha_i + \beta_k + \delta_t + \varepsilon_{ikt}$$
$$i = 1.,...,4, \quad k = 1.,...,4, \quad t = 1,...,100 \tag{68}$$

where

Y_{ikt} is the observation when tillage system i is used and kth level of nitrogen applied at time t.

μ is the overall population mean

α_i the tillage effect

β_k is the treatment level effect

δ_t is the year effect assumed to be iid N(0, σ^2)

ε_{ikt} is the experimental error associated with Y_{ikt}, assumed to be iid N(0, σ^2)

In matrix notation

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{Z}\mathbf{u} + \mathbf{e} \tag{69}$$

where

y is the vector of observations

X is the matrix of fixed effect

β is the vector of parameters associated with fixed effects

Z is the matrix of random effect

u is the matrix of experimental errors, assumed to be MVN(0, G)

e is the vector of measurement errors, assumed to be MVN(0, R)

β, G and R are estimated using MLE. Then a generalized least squares estimator is found using the covariance matrix of **y,** which is:

$$\mathbf{V= ZGZ' +R}$$

Functional Form

1. Yield Function Much research has attempted to determine input-output relationships for a variety of agricultural processes, including the response of crop yield to nutrients. The choice of the functional form is crucial because the optimal production and input use depends on the functional form of the production function. Crop yield response to fertilizer has traditionally been specified as polynomial functions such as the quadratic or square roots forms. Llewelyn and Featherstone (1996) estimated the following quadratic and square root functions:

$$Y_i = \alpha_0 + \alpha_1(N_i) + \alpha_2(W_i) + \frac{1}{2}\beta_1(N_i)^2 + \frac{1}{2}\beta_2(W_i)^2 + \beta_3(N_iW_i) + \varepsilon_t \qquad (70)$$

$$Y_i = \alpha_0 + \alpha_1(N_i) + \alpha_2(W_i) + \beta_1(N)^{\frac{1}{2}} + \beta_2(W_i)^{\frac{1}{2}} + \beta_3(N_iW_i)^{\frac{1}{2}} + \varepsilon_t \qquad (71)$$

where

Y_i is corn yield in bushels

N_I is nitrogen applied in pounds

Wi is irrigation water in inches

α_i, β_i are parameters.

The following restrictions are imposed, $\alpha_1,\alpha_2>0$, $\beta_1,\beta_2<0$. If $\beta_3>0$, the factors are complementary, competitive if $\beta_3<0$, and independent if $\beta_3=0$.The square root function is strictly concave if β_1, β_2, $\beta_3>0$.

These functions are easy to estimate because they are linear in parameters. They exhibit diminishing marginal productivity and input substitution. They have been criticized because they force input substitution, do not allow for plateau growth, and often over-estimate optimal fertilizer use (Ackello-Ogutu et al., 1985).

Much recent interest has focused on functional forms, which allow for a growth plateau such as the von Liebig , the Mitscherlich-Baule, and the nonliear von Liebig response functions. The von Liebig function is represented by the equation

$$Y_i = \min\left[Y_m, \alpha_1 + \beta_1(N_i), \alpha_2 + \beta_2(W_i)\right] + \varepsilon_t \qquad (72)$$

where

Y_m is the maximum yield when nitrogen and water are not limiting factors. The von Liebig response function imposes an elasticity of substitution of zero a priori and a plateau growth. This implies right-angle isoquants. Thus, plants respond linearly to a nutrient until another becomes limiting and will achieve a yield plateau when neither factor is limiting. Ackello-Ogutu et al. (1985) found that the von Liebig function was preferred to both the square root and quadratic forms and that the square root was slightly better than the quadratic. Grimm et al. (1987) also found support for the Von Liebig function.

Mitscherlich-Baule response function is represented by the following equation

$$Y_i = \beta_1 * (1 - EXP(-\beta_3(\beta_4 + N))) * (1 - EXP(-\beta_5(\beta_6 + W))) + \varepsilon_t \qquad (73)$$

The parameter β_1, is analogous to Y_m in the von Liebig specification representing an asymptotic yield plateau. The parameters β_4 and β_6 may be regarded as levels of nitrogen and water, respectively, that are inherent in the production system; that is, the residual nutrient and water levels in soil prior fertilization or irrigation (Beattie & Taylor, 1985). Using non-nested test developed by Davidson & McKinnon (1981), FranK et al. (1990) found that the Mitscherlich-Baule model for corn growth was preferred to both the quadratic and von Liebig functional forms.

The functional form of the nonlinear von Liebig is indicated as follow:

$$Y_i = \min\left[m * (1 - k_1 EXP((-\beta_1 * N))), m * (1 - k_2 EXP((-\beta_2 * W)))\right] + \varepsilon_t \qquad (74)$$

This model imposes a yield plateau and non-substitution among inputs as in the linear specification, but allows for decreasing marginal productivity and decreasing returns to scale in inputs. Paris (1992) used the same data as Frank et al. (1990) to show that the nonlinear von Liebig model out-performed the quadratic, square root, linear von Liebig, and Mitscherlich-Baule specifications.

Llewelyn and Featherstone (1997) used simulated data for irrigated corn in Western Kansas to compare quadratic, square root, von Liebig, Mitscherlich-Baule, and nonlinear von Liebig production functions. The J-test and P-test procedures were used to make the comparisons temporarily holding each functional form as the null hypothesis and making a pair-wise comparison with each alternative. With both the J- and P-tests, the Mitscherlich-Baule was favored over both the von Liebig linear and nonlinear specifications. When the J-test was used, the quadratic was not rejected, but the square root was rejected at 1%, but not at 5% significance when compared with the Mitscherlich-Baule. However, when the P-test was used, both of these polynomials were rejected in favor of the Mitscherlich-Baule.

The functional form used in this study is a modified version of the Mitscherlich-Spillman (M-S) function, which is a version of the Mitscherlich-Baule response function. The M-S function often used in economic studies of soil erosion (Taylor 1982, Young et al. 1985), is expressed as:

$$Y_t = Y_m - \alpha * EXP(\beta_1 1/D_t + \beta_2 1/N_t + \beta_3 1/TNO3_t) + \varepsilon_t \qquad (75)$$

Where

Y_t	is yield in metric tons per hectare
Y_m	is the maximum attainable yield
$1/D_t$	is the inverse of topsoil depth at time t (m)
$1/N_t$	is the inverse of applied nitrogen at time t (kg/ha)
$1/TNO3_t$	is the inverse of residual nitrogen in soil at time t
α, β_1, β_2, β_3	are parameters

The function can be written as:

$$Y_t - Y_m = \alpha * EXP(\beta_1 1/D_t + \beta_2 1/N_t + \beta_3 1/TNO3_t)$$

Taking the natural log on both sides yields:

$$Ln(Y_t - Y_m) = Ln(\alpha) + \beta_1 1/D_t + \beta_2 1/N_t + \beta_3 1/TNO3_t \qquad (75')$$

This linear function was estimated to determine the parameters α and β's.

2. Nitrogen Carryover, Nitrogen Loss, Erosion Functions The functions of nitrogen carryover, nitrogen loss and erosion were estimated as linear functions of soil depth, applied nitrogen, nitrogen carryover, and tillage systems.

Nitrogen carryover was expressed as:

$$TNO3_{jt+1} = \beta_{ij} + \beta_1 D_{jt} + \beta_2 N_{jt} + \beta_3 TNO3_{jt} + \sum_{1}^{3} b_i T_i + e_{jt} \qquad (76)$$

Nitrogen loss was expressed as:

$$Nloss_{jt} = \alpha_{ij} + \alpha_1 D_{jt} + \alpha_2 N_{jt} + \alpha_3 TNO3_{jt} + \sum_{1}^{3} a_i T_i + e_{jt} \qquad (77)$$

The erosion function was estimated as:

$$E_{jt} = \rho_{ij} + \rho_1 D_{jt} + \sum_{1}^{3} c_i T_i \qquad (78)$$

Estimating Offsite Damage Costs

Miranowski (1986) asserts that both topsoil and erodibility were significant in explaining county and farm level differences in land values. Soil erosion causes both erosion-induced productivity loss and off-farm damages. In this study two types of off-farm costs were considered, the cost of erosion due to productivity loss of soil for alternative uses, and the damage cost due to nitrogen loss. Landowners do not bear the off-farm costs; therefore they have no incentive in reducing these costs. Soil erosion rates that maximize landowners' profit, therefore, will not be socially optimal. Ideally, the level of erosion control is determined by the marginal condition as described in the conceptual framework. In this process, the offsite damage costs from soil erosion are estimated and the marginal damage cost per unit of eroded soil (or the marginal benefit per unit of erosion reduced) is compared with the marginal treatment cost. The socially optimum erosion control is the level that equalizes the marginal social treatment cost and the marginal social benefit or value of damages avoided.

This approach requires knowledge of the damage functions from soil erosion, nitrogen loss, and treatment costs of all farms where eroded soil and nitrogen leakage could potentially cause damage to the environment resources down stream. According to Crosson and Brubaker (1982), the estimation of off-site benefits can be taken up in three steps. The first is to develop a model to describe the transport and distribution of eroded soil from the point where erosion occurs to the different points where damage occurs. The second step is to develop an environmental quality response function that gives, for example the change in water quality as a result of a one-ton change in the sediment or 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.

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 costs. The ultimate objective of any such policy should be to internalize the external costs of soil erosion so that farm operators would bear these costs and as a result choose a socially optimal level of erosion control.

The data to estimate the offsite damage costs in the study area are not available. Rebaudo and associates (1990) estimated that the value of annual average productivity loss of soil erosion was 42 cents per metric ton of soil erosion for the United States and 24 cents for the Southern Plains region. They estimated that the off-site damage costs 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 costs for the study area. Three levels of erosion charge were selected and included in the model. There were: $0.75, $1.50, and $2.25 per ton of eroded soil. These rates correspond to $7500, $15000 and $22500, respectively per meter per hectare reduction of soil depth as a result of erosion. By analogy, three damage cost levels of nitrogen loss were chosen. They were $0.30, $0.40 and $0.55, respectively. The private decision model was modified by subtracting these tax payments due to soil loss from the returns in the objective function to set up the social decision model.

Choice of Discount Rate

The choice of the discount rate will affect the net present value of returns. A high discount rate favors investments, which have near term returns. A low discount rate will favor investments with returns in the more distant future. The selection of the discount rate involves practical and ethical or philosophical considerations leading to tradeoffs between current and future generations. An observed or market rate of discount consists of four factors:

- the real or true rate of discount (r)
- a percentage rate of return to account for inflation (f)
- a percentage rate to account for the risk factor (e)
- a tax rate (t)

Assuming the nominal rate is (i), the before tax discount rate is expressed as:

$r = i - f - k.$

Several theories have been proposed in determining the discount rate. According to the "Crowding Out Theory", the economy is closed or has limited opportunities for capital imports or exports. Money for public investment reduces money available for private investment. As a result, Baumol (1978) argues that opportunity cost of capital should be a weighted sum of returns on displaced private investment and the value of forgone consumption or the interest rate on savings. Lind (1990) argues however that little crowding out occurs in an open global economy and the appropriate rate is the rate the public must pay for its borrowing.

Proponents of the "Social Time Preference Theory" assert that the social discount rate should be set lower than the individual rate on savings to reflect concern for future generations. The Office of Management and Budget (OMB) has recommended a real rate of 10% to reflect foregone opportunities in the private sector. The US Water Resource Council chose the long-term rate on treasury bonds, a nominal but legislated rate, which averaged 7.8% during the 1980's. The US Forest Service uses 4%, which is reached after an analysis of the real long-term rate of corporate. This is a before tax rate which excludes risk.

In summary, the discount rate should reflect the social opportunity cost of capital, which includes the risk less cost of capital plus a risk premium that depends on the nature of the investment. Following Aw Hassan (1992), this study chose an 8% discount rate. This rate was determined using an iterative method to find a discount rate, which most closely equated the expected future earnings to the actual sale price of individual tracts of farmland sold in Grant County.

Optimization Method

The model specified in equation (59) through equation (65) requires solving a large number of equations. Dynamic programming method would be a problem because there are an infinite number of possible state variables corresponding to soil depths per tillage system. Given this complexity the study proposes a branching method to simplify the solution. A schematic diagram of the method is presented in Annex C. The method consists of decomposing the optimization problem into a large number of smaller optimization problems. In this process, the problems are solved independently at each soil level. The model is modified as follows:

$$\underset{N,M}{Max}\, NPV = \sum_{t=1}^{T}\sum_{i=1}^{I}\bar{A}\begin{bmatrix} P_y Y_{it}(D_t, N_t, TNO3_t, \bar{M}_{it}) - VC_t(N_t, \bar{M}_{it}) \\ -t_n Nloss_t - t_e E_{it}) \end{bmatrix}(1+r)^t \quad (79)$$

Subject to:

$$D_{t+1} = D_t - E_{it}(D_t, \bar{M}_{it}) \quad (80)$$

$$D_t = \bar{D}_1 \quad (81)$$

$$\sum_{i=1}^{I}\bar{M}_{it} = 1 \qquad for\, all\, t \quad (82)$$

$$Nloss_t = f(D_t, N_t, TNO3_t) \qquad (83)$$

$$TNO3_{t+1} = g(D_t, N_t, TNO3_t) \qquad (84)$$

$$TNO3_t = \bar{TNO3}_1 \qquad (85)$$

$$D, M, N, TNO3 > 0$$

The approach will be to select a sequence of tillage system over the planning horizon. The initial soil depth is known for each soil type. The only remaining variable to determine is the rate of nitrogen application. The next step is to change a tillage system, resolve for the optimal fertilizer, and see if the net present value can be increased. Thus, the optimization problem consists in finding the optimum level of applied nitrogen that gives the highest net present value obtained from the use of a given tillage system for each investment period. The specific steps for solving the optimization problem are as follows: on a given soil type, an arbitrary sequence of tillage systems is specified for all investment periods. Assuming a 10-year investment period, the following sequence of tillage system is specified for the 50-year planning period:

Period	Tillage Sequence
1-10	Disk Chisel
11-20	Sweep System Once
21-30	Plow
31-40	Sweep System Twice
41-50	Disk Chisel

Beginning with the first period (1-10), compute for each year the net present value for tillage system disk chisel for this period while maintaining the same sequence of tillage systems as specified above for the other investment periods. Calculate the net present value soil by soil and find the level of applied nitrogen that gives the maximum net present value for each soil. Then go to the next tillage system, compute, and find for each soil the maximum net present value. After going through all the tillage systems, record the tillage with the highest net present value of this first period. Assume for example tillage sweep system once has the highest net present value; this system is now used for the period 1-10 years. The resulting sequence is as follow:

Period	Tillage Sequence
1-10	*Sweep System Once
11-20	Sweep System Once
2130	Plow
31-40	Sweep System Twice
41-50	Disk Chisel

Now considering the period 11-20, assume the sequence disk chisel, plow, sweep system twice and sweep system twice was used. By the same process described above, find, by going through every soil type, which tillage system gives the maximum net present value. Assume tillage system disk chisel has the highest net present value. Thus, this system is used for the period 11-20. The tillage sequence is shown below.

Period	Tillage Sequence
1-10	*Sweep System Once
11-20	*Disk Chisel
2130	Plow
31-40	Sweep System Twice
41-50	Disk Chisel

Now consider the period 21-30 and try the sequence disk chisel, plow, sweep system twice, sweep system once and find out which has the highest net present value, say tillage system disk chisel. Now the tillage system sequence is:

Period	Tillage Sequence
1-10	*Sweep System Once
11-20	*Disk Chisel
2130	*Disk Chisel
31-40	Sweep System Twice
41-50	Plow

Repeat the process for the periods 31-40 and 41-50 and find the optimum tillage systems for these periods. After finishing with the year 50 and finding an optimum tillage for each of the five periods, ask whether we were able to improve the net present value by choosing a different tillage system in any of the 10-year investment periods. If no, stop. If there is room for improvement, go back and repeat the process beginning with year 1. The process will stop when we have a sequence of tillage systems such that we are unable to find a higher net present value by changing to another tillage system. This solution gives the optimum tillage systems and rate of applied nitrogen.

CHAPTER V

RESULTS

This section reports the results of the statistical estimation of the functions of yield, nitrogen loss, residual nitrogen and erosion, and the results of the optimization of private and social profit. The results of the regression analysis were first used to predict the long-run variation of the estimated functions and to assess the impact of different tillage systems and soil type. Each simulation was for a 100-year period. Explanatory or independent variables were held constant. Then the optimization model was set up for a base line solution. The purpose of the optimization was to find the optimal level of the variable under the control of the decision maker. A sensitivity of farm income and environmental outcome of several economic policies pertaining to changes in product prices, discount rates, and off-site damage costs were compared. The analysis made at individual soil type and farm levels was based on the scenarios described on Table 2.

Statistical Estimation

Erosion Function

A simple linear function of soil depths and tillage systems was used to estimate the erosion function. The dependant variable was annual erosion generated by the USLE option in EPIC, expressed in metric tons per hectare. This variable was converted to

Table 2. Optimization Scenarios

Scenarios	P_y[a]	P_N	DR	T_e	T_{NL}
	$/MT	$/kg	%	$/m	$/kg
1. Baseline solution with offsite cost	110	0.55	8	15000	0.35
2. Baseline solution without offsite cost	110	0.55	8	0	0
3. High product price with offsite cost	132	0.55	8	15000	0.35
4. High product price without offsite cost	132	0.35	8	0	0
5. Low product price with offsite cost	88	0.35	8	15000	0.35
6. Low product price without offsite cost	88	0.35	8	0	0
7. High nitrogen cost with offsite cost	110	0.66	8	15000	0.35
8. High nitrogen cost without offsite cost	110	0.66	8	0	0
9. Low nitrogen cost with offsite cost	110	0.44	8	15000	0.35
10. Low nitrogen cost without offsite cost	110	0.44	8	0	0
11. High discount rate with offsite cost	110	0.35	10	15000	0.35
12. High discount rate without offsite cost	110	0.35	10	0	0
13. Low discount rate with offsite cost	110	0.35	4	15000	0.35
14. Low discount rate without offsite cost	110	0.35	4	0	0
15. High offsite cost	110	0.35	8	22500	0.55
16. Low offsite cost	110	0.35	8	7500	0.18

[a] P_y = product price, P_N = price of nitrogen, DR = discount rate, T_e = tax on erosion, T_{NL} = tax on nitrogen loss

Table 3. Erosion Function per Soil Type (meters)[a]

	$D(\rho_1)$	$DC(c_1)$	$PL(c_2)$	$SW1(c_3)$	$I^b(\rho 4_j)$
Kirkland	-3.63150	1.43957	9.58617	-0.03723	7.65217
	(-3.06)[c]	(9.48)	(16.27)	(-2.66)	(3.18)
Miller	-1.17541	0.39412	3.79802	-0.01149	2.69678
	(-4.46)	(8.51)	(16.06)	(-2.67)	(4.46)
Norge	-12.79093	2.35912	23.44956	-0.13195	22.03730
	(-4.30)	(8.14)	(16.35)	(-4.65)	(5.64)
Renfrow	-2.57644	1.16063	8.08730	-0.04332	5.17912
	(-2.34)	(9.17)	(13.94)	(-3.28)	(2.49)
Vernon	-10.92993	2.84065	16.61162	-0.05153	22.72413
	(-6.96)	(9.76)	(15.26)	(-1.99)	(7.16)
Zanies	-6.38907	2.35351	13.50549	-0.08329	10.26323
	(-3.32)	(9.32)	(14.11)	(-3.27)	(3.52)

[a] $\text{Erosion(m)} = \rho_1 D + c_1 DC + \rho_{PL} PL + \rho_{SW1}\, \rho SW1 + \rho_I I$ (equation 78)
T_i replaced by tillage system DC, PL, SW1

[b] I is intercept representing tillage sweep system twice excluded dummy variable for each soil type j

[c] t-values in parenthesis

meters using a conversion factor calculated for each combination of tillage system and soil type, using the bulk densities of the different soils. Table 29 in Annex B gives the different conversion factors used. The results of the estimation are shown on Table 3. All the coefficients are significantly different from zero at the 5% significant level and have the expected sign. The results indicate that as topsoil depth decreases, the amount of erosion generated increases across all soils. The size of the coefficient of the variable soil depth varies considerably by soil type reflecting possible differences in erosion effect on these soils. The coefficients of the tillage systems are also considerably different. The coefficients of the tillage system plow are the highest for all soil. Table 4 reports the average amount of erosion taken over 100 year-period from EPIC simulation data, and predictions using the estimated erosion function.

Table 4. Average Simulated and Predicted Erosion (MT/ha)[a]

Soil	Slopes	DC		PL		SW1		SW2	
Types		Simu[b]	Pred[c]	Simu	Pred	Simu	Pred	Simu	Pred
Kirkland	0.02	2.18	2.03	11.45	11.06	0.24	0.24	0.30	0.30
Miller	0.005	0.67	1.04	4.57	4.39	0.08	0.08	0.09	0.09
Norge	0.04	4.36	3.98	29.58	28.37	0.50	0.45	0.63	0.60
Renfrow	0.02	1.14	1.64	11.21	9.32	0.24	0.25	0.28	0.30
Vernon	0.04	4.54	4.63	21.11	21.43	0.47	0.55	0.62	0.59
Zanies	0.04	4.01	3.45	17.36	16.31	0.46	0.47	0.56	0.59

a Average taken over 100 years; average annual weather conditions for each soil and tillage system were used in the simulation

b Simu=Simulated form EPIC

c Pred=Predicted by model.

The results show that the model predicts well the data generated by EPIC. Except for Miller soil, when disk chisel was used, the predicted erosion rates are very close to the simulation figures. The model was able to make several perfect predictions of the amount of erosion caused by the use of different tillage systems.

Figures 4 and 5 show the variation of soil erosion over time on Kirkland and Renfrow soils as predicted by the estimated erosion function. There seems to be little change over time for all the tillage systems. However, conventional systems have consistently higher erosion rate at all times than conservation systems. The graph of the other soils is not shown, but the trend is the same for all soils.

Yield Response Function

1. Choice of Functional Form J-test was used to compare the suitability of the modified M-S function and the quadratic function. The quadratic function was expressed as:

$$Y_t = \alpha_0 + \alpha_1 D_t + \alpha_2 N_t + \alpha_3 TNO3_t + \alpha_4 D_t^2 + \alpha_5 N_t^2 + \alpha_6 TNO3_t^2 + \alpha_7 D_t N_t + \alpha_8 D_t TNO3_t + \alpha_9 N_t TNO3_t + \varepsilon_t \quad (86)$$

where D_t, N_t, and $TNO3_t$, are as previously defined.

The J-test is defined as:

$$Y_t = (1-\alpha)e_t + \alpha \hat{g}_t + \varepsilon_t \quad (87)$$

where e_t is the M-S function (equation 75') and $\hat{g}_t$ is the estimated quadratic function (equation 86) using the estimated parameter values. The null hypothesis being tested was H_0 $\alpha=0$, the M-S function was a better model against the alternative hypothesis $\alpha \neq 0$, the

Figure 4. Variation of Erosion over Time per Tillage System on Kirkland Soils

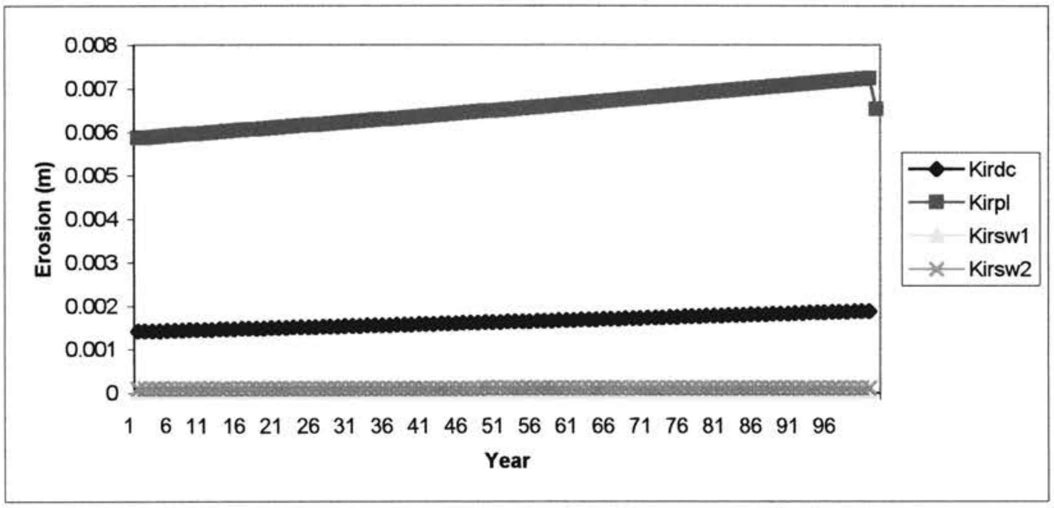
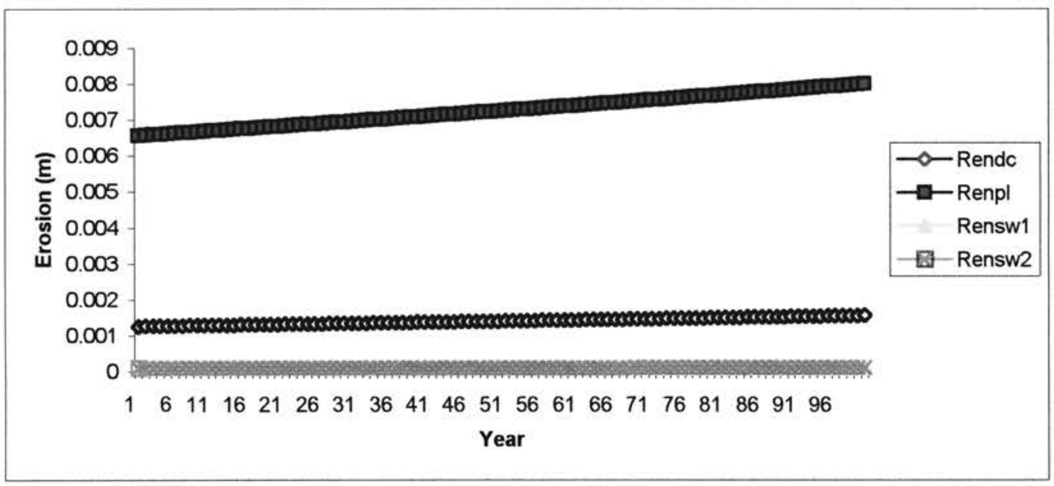


Figure 5. Variation of Erosion over Time per Tillage System on Renfrow Soils



quadratic function was the better model. The reason is that, if $\alpha=0$, the quadratic function does not contribute in explaining the yield function. The test was also performed when in equation (87), e_t represented the quadratic function and $\hat{g}_t$ the estimated modified M-S function. In this case, the null hypothesis $\alpha=0$ indicated that the quadratic specification was a better model and the alternative $\alpha\neq0$ meant that the modified M-S function was a better model.

The M-S and quadratic functions were estimated using the linear estimation method while the J-test model requires nonlinear estimation techniques. All models linear were estimated using SAS PROC MIXED PROCEDURES while PROC NL was used for the non-linear estimation.

The results of the test reported on Table 5 were ambiguous as it is possible in a pair-wise comparison using the J-test. They indicate that α was significantly different from 0 at the 5% significant level for all soil types, whether the null hypothesis was the

Table 5 Results of the J-test Comparing the Modified M-S and Quadratic Functions of Yield

Soil	M-S Function				Quadratic Function		
Type	α	Std. Error	Lo. Limit	Up. Limit	α	T	Pr
Kirkland	0.98179	0.01415	0.95402	1.00957	-1.81162	-4.76	0.0001
Miller	0.95646	0.05068	0.85705	1.05587	-1.13359	-3.19	0.0015
Norge	0.88266	0.05835	0.76819	0.99713	-1.90124	-6.19	0.0001
Renfrow	0.92686	0.04423	0.84008	1.01363	-2.02681	-5.37	0.0001
Vernon	0.83957	0.06275	0.71648	0.96266	-3.14341	-6.76	0.0001
Zanies	0.98829	0.01097	0.96675	1.00983	-1.85484	-3.91	0.0001

M-S or quadratic function, indicating that both models are preferred to the other. Based on the results of the test and the criticism of the quadratic function expressed by Ackello-Oguttu et al., (1985), the M-S function was preferred to the quadratic specification as a functional form of the yield function in this study.

2. Estimation Results Table 6 shows the estimated coefficients and t-values for the M-S yield function of the individual soil types. Numbers in parenthesis are t-statistics. The yield function was first estimated with dummy variables for tillage systems included as explanatory variables that were finally dropped because their coefficients were not significantly different from zero for most tillage systems. The exclusion of these dummy variables reflects prior research that indicates no significant difference in grain yield among tillage systems (Ellis et al.1983).

As Table 6 shows all the estimated coefficients, except the coefficient of soil depth for the Vernon soil type, are significantly different than zero at the 5 percent significant level, and have the expected sign. The size of estimated coefficients indicates that applied nitrogen has bigger marginal effect on yield than residual nitrogen across all soil types.

Table 6 also indicates that the change in yield per unit change in soil depth is relatively higher for Zanies, Miller and Kirkland soil than for the Renfrow and Norge soils. Changes in Vernon soil type depth had almost no effect on yield.

The EPIC and predicted yields per soil type and tillage system averaged over a 100-year period are shown on Table 7. The predictions were made by holding the rate of applied nitrogen constant at 100 kg per ha per year. It appears that there is little difference among tillage systems across all soil types. The average predicted yields over

Table 6. Wheat Yield (metric ton per hectare) Response[a] to Nitrogen, Soil Depth, and Residual Nitrogen Based on EPIC Simulation Data

Soil Types	Intercept $Ln(\alpha)$[b]	1/D (m) β_1	1/N (kg/ha) β_2	1/TNO3(kg/ha) β_3
	Estimated Coefficients			
Kirkland	0.47610910	0.3350949	20.16689429	10.11447447
	(8.01)[c]	(3.37)	(11.41)	(12.00)
Miller	0.49531218	0.3224701	17.0308516	8.4305711
	(12.74)	(6.52)	(10.96)	(12.91)
Norge	0.63602100	0.1582439	14.9809890	10.42199320
	(14.46)	(2.57)	(8.91)	(16.14)
Renfrow	0.05550740	0.2619056	23.3569976	8.92823618
	(8.73)	(3.02)	(11.44)	(10.93)
Vernon	0.96222608	0.0595569	9.9256043	5.24858910
	(37.89)	(1.38)	(8.20)	(15.29)
Zanies	0.59082905	0.3319812	18.7738398	5.50224202
	(16.26)	(7.70)	(12.16)	(10.25)

[a] $Ln(Y_t-Y_m)=Ln(\alpha) + \beta_1\ 1/D_t + \beta_2\ 1/N_t + \beta_3 1/TNO3_t$ (Equation 75')

[b] Coefficients were estimated by using SAS (PROC MIXED) procedures. Data were observations for each soil type

[c] T-values in parenthesis.

100 year- period are 3.8 Mt/ha for tillage systems plow, sweep once, and sweep twice on Miller soil type. They are 3.66 MT/ha on Norge soil type, for tillage systems disk chisel, sweep system once, and sweep system twice. The average predicted yield for soil type Renfrow varies between 3.69MT/ha and 3.70MT/ha across all tillage systems. The average yield per tillage system across all soil types is almost constant at 3.5 MT/ha.

Yield differences are more noticeable among soil types than among tillage systems. The average predicted yield varies from 3.8 MT/ha on Miller soil to 2.93 MT/ha on Vernon soil. The highest average yield was obtained on Miller soil type using tillage systems plow, sweep system once, and sweep system twice. The lowest average yield was obtained from Vernon soil type, using tillage system plow.

Table 7 also shows average observed yield from EPIC data when the rate of applied nitrogen was 100 kg/ha. In general the data and the results of the estimation seem to indicate the same tendency of no difference in yields among tillage systems and relatively higher differences in yield among soil types. However, the simulation data seems to suggest more differences in yield among tillage systems than indicated by the predictions of the model. Compared to observed data, the average predicted yields seem to be consistently higher as reflected in either the average yield by soil type or tillage system. These results seem to suggest that the model over estimated yield levels.

Table 7. Average Observed and Predicted Yield per Tillage System and Soil Type with 100 kg/ha of applied nitrogen (MT/ha)[a]

	Disc Chisel		Plow		Sweep Once		Sweep Twice		Average	
	Simu	Pred	Simu	Pred	Simu	Pred	Simu	Pred	Simu	Pred
Kikland	3.36	3.58	3.15	3.63	3.51	3.50	3.51	3.57	3.38	3.57
Miller	3.30	3.71	2.95	3.80	3.45	3.80	4.14	3.80	3.46	3.78
Norge	3.29	3.66	3.00	3.62	3.41	3.66	3.42	3.66	3.28	3.65
Renfrow	3.35	3.69	3.15	3.68	3.50	3.70	3.50	3.70	3.38	3.69
Vernon	2.71	2.93	2.61	2.90	2.88	2.94	2.88	2.94	2.77	2.93
Zaneis	3.10	3.46	2.74	3.43	3.26	3.46	3.26	3.46	3.09	3.45
Average	3.19	3.51	2.93	3.51	3.34	3.51	3.45	3.52		

[a] Average taken over 100 years; average annual weather conditions and erosion rates for each soil and tillage system were used

3. Yield Response Function Validation The results of the estimation of the yield function were adjusted to take into account the actual yield of wheat production in Oklahoma. Data were collected from wheat variety trials conducted on farmer's fields in North Central Oklahoma on Dale, Renfrow, Pond Creek, Bethany, Kirkland, and Grant soils, from 1990 through 1998. The average yield from Cimarron, Chisholm, Karl, 2180 and 2136 varieties was calculated at each location. The results were regressed against 0-1 variables for the soil types. The expected average yields from the trials on farmer's fields were found to be:

$$Y = 33.223 - 8.186D_B + 7.11D_g + 16.49d_{ren} + 10.33D_{pc} \qquad (32)$$

where:

D_B is dummy variable for low years, D_B=1 for 1993, 1995, and 1996

D_G is dummy variable for good years, D_G=1 for 1997 and 1998

D_{ren}=1 for trials on Renfrow soil and 0 otherwise

D_{Pc}=1 for trails on Pond Creek soil, 0 otherwise

The estimated mean yield for Kirkland soil type is 32.07 bushels per acre or 2.16MT/ha. This result was used to adjust the yields from the coefficients in Table 6 to represent farm level yields for each soil type. The yield variety trials are generally conducted on soils with smaller slopes than the average slope over an entire soil series. The next step was to adjust for increased slope and past erosion. In Table 8, the yield for the different soils was adjusted so as to maintain relative productivity and proportionate effect of technology on each soil. The estimated yields were adjusted by changing the intercept of the estimated yield function of each soil type.

The average adjusted yields over the 100-year period per tillage system and soil type are reported on Table 9 along with the estimated yields previously reported on Table 4.

Table 8. Potential Yield, Estimated and Adjusted Intercept of Yield Function per Soil Type

Soil Type	Maximum Depth (m)	Soil Slopes	Potential Yield (MT/ha)[c]	Estimated Intercept[a]	Adjusted Intercept[b]
Kirkland	2.01	0.02	1.89	0.4761	2.0228
Miller	1.52	0.005	1.98	0.4953	2.0969
Norge	1.68	0.04	1.91	0.6360	2.4025
Renfrow	1.9	0.02	1.89	0.0555	2.0129
Vernon	2.03	0.04	0.71	0.9622	4.0068
Zanies	1.51	0.04	1.80	0.5909	2.0267

[a] Estimated intercept from simulation data (Table 6)
[b] Adjusted intercept to obtained adjusted yield
[c] Source:

In general, the difference between the estimated and adjusted yields is less than 25%. The adjusted yields follow the same pattern of yield variation per tillage system and soil type as described above. That is, for a given depth of soil, the wheat yields for each tillage system are almost identical, varying from 2.61 MT/ha to 2.68 MT/ha, except for the plow system. The plow system has an average yield of only 2.3 MT/ha because of higher annual erosion.

Differences in yield variation per soil type are more important. The average yield varies from 3.02 MT/ha to 1.17 MT/ha. Figure 6 shows yield variation over soil depth per soil type. The results show that Vernon has very low productivity, which varies from 1.15 MT/ha to 1.45 MT/ha at different levels of soil depth. The average yields of the other soil types are close to one another when top soil depth is more than 1 m, ranging from 2.4 MT /ha to 3.14 MT/ha. The average yield of Renfrow soil type remains slightly higher at every level of topsoil. Yields decrease more rapidly when soil depth is below 1 m with the largest decline coming from Kirkland soil type falling from 2.4 MT/ha to 1.38 MT/ha when topsoil depth decreases from 1m to 0.6 m.

Yield variation over time per tillage system on Kirkland and Renfrow soil types with a combined area of more than 70% of the study area, are shown on Figure 7 and Figure 8, respectively. The type of variation is similar on both graphs. At the beginning of the planning period, the highest yield was obtained using the plow system. This trend continues for the first 25 years for Kirkland soil type and the first 5 years for Renfrow soil type, and then the yield declines throughout the period, remaining lower than the yield obtained using conservation tillage systems. During the 100 years of simulation, the estimated and adjusted yield of the tillage system plow decreased from 3.02 MT/ha to

2.09 MT/ha on Kirkland soil type and from 3.09 MT/ha to 2.19 MT/ha on Renfrow soil type.

Table 9. Average Estimated and Adjusted Yield per Tillage System and Soil Type (MT/ha)

	Disc Chisel		Plow		Sweep Once		Sweep Twice		Average	
	Pred[a]	Adju[b]	Pred	Adju	Pred	Adju	Pred	Adju	Pred	Adju
Kikland	3.58	3.01	3.63	2.80	3.50	3.02	3.57	3.06	3.57	2.22
Miller	3.71	2.78	3.80	2.42	3.80	2.90	3.80	2.90	3.78	2.75
Norge	3.66	2.82	3.62	2.54	3.66	2.87	3.66	2.87	3.65	2.77
Renfrow	3.69	3.07	3.68	2.80	3.70	3.11	3.70	3.11	3.69	3.02
Vernon	2.93	1.20	2.90	0.99	2.94	1.25	2.94	1.25	2.93	1.17
Zaneis	3.46	2.81	3.43	2.26	3.46	2.90	3.46	2.90	3.45	2.71
Average	3.51	2.61	3.51	2.30	3.51	2.67	3.52	2.68		

[a] Predi=Predicted using the estimated function

[b] Adju=Adjusted

Figure 6.Yield Response per Soil Type with 100 kg/ha of Applied Nitrogen

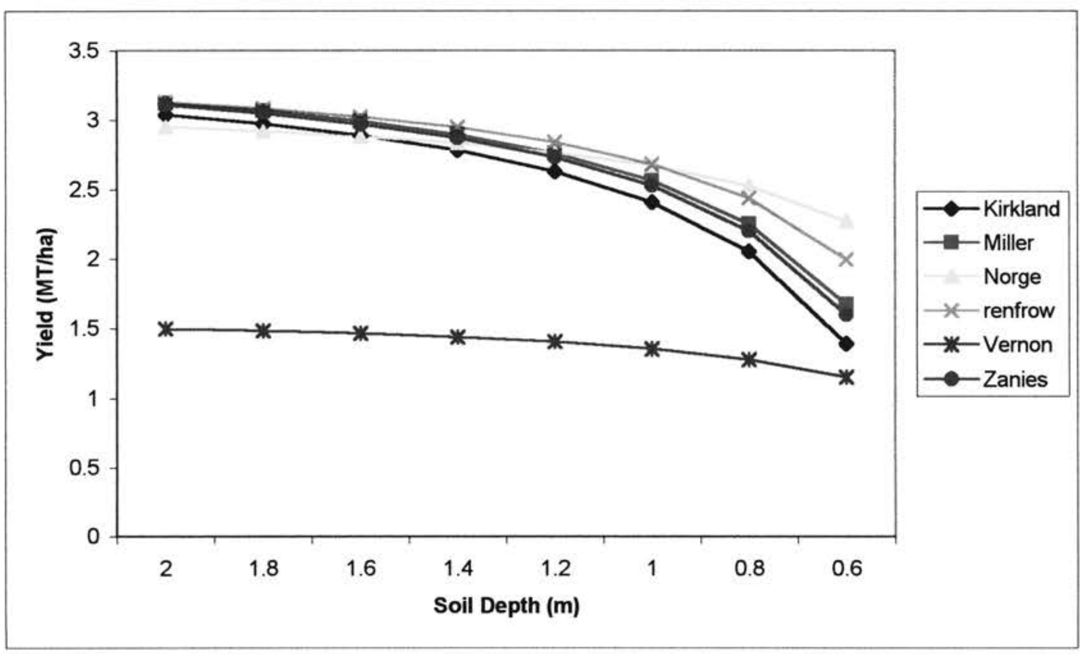


Figure 7. Yield Variation over Time per Tillage System on Kirkland Soil With 2% Slope and 100 kg/ha of Nitrogen

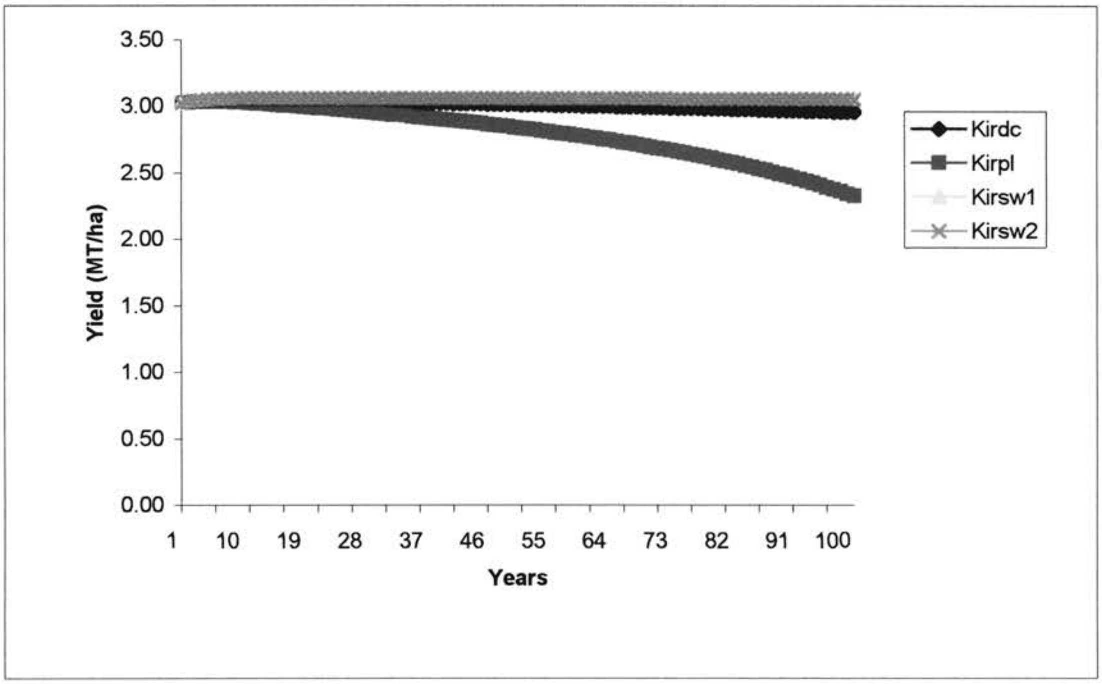
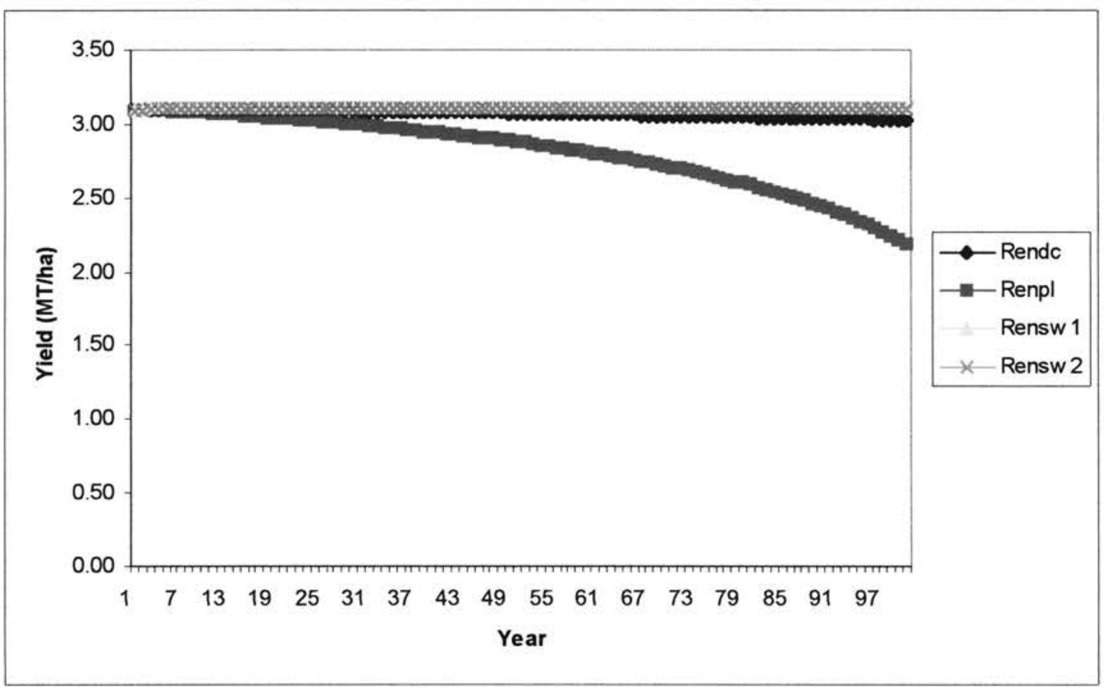


Figure 8. Yield Variation over Time per Tillage System on Renfrow Soil With 2% Slope and 100 kg/ha of Nitrogen



The use of tillage systems, sweep system once, sweep system twice, and disk chisel caused almost no variation in yield over time on either Kirkland or Renfrow soil type. However, disk chisel system has a slightly lower yield throughout the period. Average yields of the three tillage systems ranged from 3.03 MT/ha to 3.11 MT/ha on both soils. This pattern of yield variation over time was similar for all soil types surveyed in this study. The main difference lies in soil slopes and erosion potential. For the Zanies soil type, yield decreased up to 0.55 MT/ha at the end of the simulation period when the plow system was used. The yields of the other tillage systems were not below 2.9 MT/ha at any time, for all the soil types except, for Vernon soil type where yield varied from 1.48MT/ha to 1.24 MT/ha. This difference in yield over time among tillage systems and soil types reflects the corresponding effect of soil depth variation on yield through erosion.

4. Effect of Erosion on Yield Table 10 reports the initial and ending soil depth of each soil type and tillage system, along with average annual soil erosion and yield at ending soil depth. The average erosion was calculated for a period of 100 years holding constant the level of applied nitrogen at 100 kg/ha. For each soil type there is at least 30 times more erosion from the plow system than there is from the sweep twice system. The rate of erosion varies between 4 MT/ha per year and 21 MT/ha per year for the plow system but is less than 1 MT/ha per year for the sweep systems.

The effect of soil erosion on yield is shown on Figure 9. As hypothesized earlier, tillage improvement is considered as land substituting technological progress. That is, as farmers invest in conservation tillage system to move away from conventional

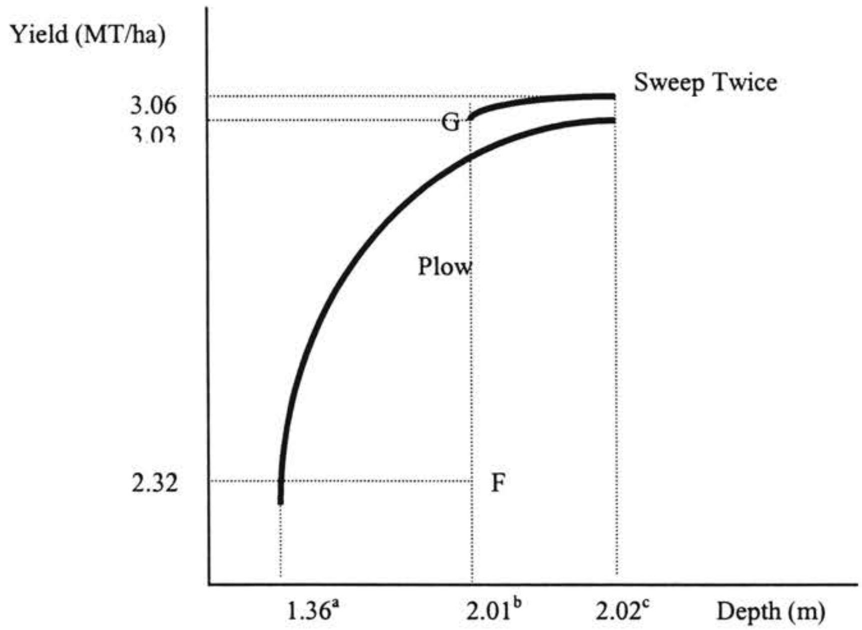
Table 10. Initial and Ending Soil Depth in Meters and Yield in MT/ha per Soil Type and Tillage System

	Disk Chisel				Plow				Sweep System Once				Sweep System Twice			
	ID [a]	ED	AE	Yield	ID	ED	AE	Yield	ID	ED	AE	Yield	ID	ED	AE	Yield
Kirkland	2.02	1.86	2.03	2.96	2.02	1.36	11.06	2.32	2.02	2.01	0.24	3.06	2.02	2.01	0.3	3.06
Miller	1.51	1.30	1.04	2.65	1.51	0.94	4.39	1.26	1.52	1.51	0.08	2.90	1.52	1.51	0.09	2.90
Norge	1.67	1.51	3.98	276	1.67	0.98	28.37	1.81	1.68	1.67	0.45	2.87	1.68	1.67	0.6	2.86
Renfrow	1.89	1.75	1.64	3.03	1.88	1.16	9.32	2.19	1.90	1.89	0.25	3.10	1.90	1.89	0.3	3.10
Vernon	2.02	1.19	4.63	1.13	2.02	1.22	21.43	0.49	2.03	2.02	0.55	1.24	2.03	2.02	0.59	1.24
Zanies	1.51	1.35	3.45	2.72	1.51	0.80	16.31	0.55	1.52	1.51	0.47	2.90	1.52	1.51	0.59	2.89

[a] ID is initial soil depth in meters, ED is ending soil depth in meters, AE is average erosion in MT/ha, Yield in MT/ha

systems, it is expected that as soil depth decreases, the difference between the yields of the two tillage systems becomes wider. On Kirkland soil, the use of sweep system twice reduced soil depth from 2.02 m to 2.01 m and decreased yield to 3.06 MT/ha after 100 years.

Figure 9. Long –Term Effect of Erosion on Yield for Kirkland Soil



[a] Ending soil depth for plow system are from Table 7
[b] Ending soil depth for sweep system twice from Table 7
[c] Beginning soil depth for Kirkland soil type from Table 7.

For the plow system, soil depth decreased to 1.36 m, and yield was 2.32 MT/ha at the end of the planning period. Thus, the effect of erosion was to reduce yield by 0.74 MT/ha indicated by the distance GF on Figure 6. This corresponds to a yield decrease of 28.92 kg/ha for every centimeter reduction in soil depth as shown on Table 11. The same analysis is conducted for the other soil types. The effects of soil erosion on yield for these soils are also reported on Table 8. Yield reductions vary from 3.18 kg/ha to 20.5 kg/ha per centimeter reduction in soil depth due to erosion. The highest yield reduction occurred on Zanies soil and the lowest on Vernon soil, where, as pointed out above, changes in soil depth had no effect on yield.

Table 11. Effect of Soil Erosion on Yield per Soil Type

	E D SW2[a] meters	Yield[b] SW2 MT/ha	ED Plow[a] meters	Yield Plow MT/ha	Yield Diff[c] MT/ha	Depth Diff[c] Meters	Yield Reduction[d] Kg/ha/cm
Kirkland	2.01	3.06	1.36	2.32	0.74	0.65	11.39
Miller	1.51	2.90	0.94	1.26	1.64	0.56	29.28
Norge	1.67	2.86	0.98	1.81	1.05	0.69	15.22
Renfrow	1.89	3.10	1.16	2.19	0.91	0.73	12.46
Vernon	2.02	1.24	1.22	0.49	0.75	0.80	9.37
Zanies	1.51	2.89	0.80	0.55	2.34	0.71	32.96

[a] ED= ending depth for sweep system twice and system plow source Table 7
[b] Yield at ending soil depth when tillage sweep system twice was used, source Table 7
[c] col.(7) = col.(3)-col.(6), col.(8)= col.(2)-col.(4)
[d] Yield reduction per inch reduction in soil depth

Nitrogen Carryover Function

1. Estimation Results Westerman et al. (1994), and Johnson and Raun (1995) are few of the studies that determined long-term wheat response to fertilizer N and evaluated the accumulation of NH_4 and NO_3 –N in soil profile. The results indicate that NH_4 and NO_3-N accumulation increased only when nitrogen rate application exceeded yield goal requirement of 90 kg/ha. A quadratic equation was used to estimate NO_3-N accumulation in relation to nitrogen application. For the Kirkland soil type, NO_3-N accumulation at 2.4 m of soil depth was 250 kg/ha.

Nitrogen carryover was estimated in this study as a linear function of soil depth (D), applied, and residual nitrogen (N and TNO3). Table 12 shows the results of the estimation. The coefficients of soil depth, applied, and residual nitrogen for all soil types are significantly different from zero at the 5% significant level. Nitrogen carryover is more affected by prior nitrogen carryover than applied nitrogen for all soils as reflected by the size of the coefficients. The results indicate that an increase in nitrogen carryover in year t by one kg/ha will increase nitrogen carryover in year t+1 between 0.69 and 0.85 kg/ha depending on the soil type. The equivalent increase in applied nitrogen will increase nitrogen carryover in year t+1 by only 0.08 to 0.28 kg/ha.

Table 13 shows average levels of nitrogen carryover for100-year period from both EPIC simulation data and the predictions of the model, assuming a rate of 100 kg/ha of applied nitrogen. The two averages are very close for all tillage systems and soil types, except for the sweep system once and sweep system twice when they were used on Miller soil type. However, in general, the average predicted TNO3 is slightly higher.

Table 12. Nitrogen Carryover Function per Soil Type (kg/ha)

Soil Type	Intercept	D	N	TNO3
Kirkland	-48.47027	22.34702	0.28521	0.75892
	(-8.27)[a]	(7.71)	(12.37)	(44.98)
Miller	-22.38876	17.37143	0.08636	0.85114
	(-5.92)	(6.98)	(7.74)	(61.38)
Norge	-31.69638	17.56365	0.20172	0.80632
	(-6.83)	(6.38)	(9.64)	(9.64)
Renfrow	-42.53226	19.92899	0.26178	0.78462
	(-8.08)	(7.31)	(11.65)	(49.89)
Vernon	-23.93376	10.82672	0.17557	0.69304
	(-7.12)	(6.49)	(11.62)	(30.41)
Zanies	-31.37741	19.99340	0.19059	0.80169
	(-8.04)	(7.86)	(10.02)	(47.95)

[a] t-values in parenthesis

Table 13. Simulated and Estimated Nitrogen Carryover (kg/ha)

	DC		PL		SW1		SW2	
	Simu[a]	Pred[b]	Simu	Pred	Simu	Pred	Simu	Pred
Kirland	97.92	97.57	76.84	76.77	94.93	104.98	106.89	104.54
Miller	72.96	74.03	57.14	56.35	64.55	85.59	145.34	95.19
Norge	85.28	86.39	64.44	65.04	83.68	92.77	97.58	92.64
Renfrow	89.45	93.15	67.33	68.73	88.05	99.28	80.06	99.19
Vernon	43.61	48.49	38.26	39.29	39.25	52.07	46.97	53.00
Zanies	78.71	83.52	56.13	59.25	76.54	91.28	70.85	90.83

[a] Simu=Simulated
[b] Pred=Predicted

Figures 10 and Figure 11 show variations in nitrogen carryover over time by tillage system on Kirkland and Renfrow soil types. Using plow system on Kirkland soil type the first 10 years resulted in an increase in nitrogen carry over from 95 kg/ha to 100 kg/ha, and a considerably decrease thereafter to 47 kg/ha at the end of the simulation period. On Renfrow soil type nitrogen carryover increased one kg/ha the first 10-years when plow system was used, then decreased by 35 kg/ha over the remaining 90 years. There was little difference in nitrogen carryover between the sweep tillage systems on Kirkland or Renfrow soils. On Kirkland soil nitrogen carryover stabilized at 105 kg/ha after the first 10 years with either sweep system, when 100 kg/ha of nitrogen was applied each year. On Renfrow soil, the trend was similar to the Kirkland soil but the nitrogen carryover peaked at 100 kg/ha. With the disk system, soil nitrogen first increased from 95 kg/ha to 103 kg/ha and from 95 to 98 on Kirkland and Renfrow soils

Figure 10. Variation of Nitrogen Carryover Over Time per Tillage System on Kirkland Soil With 2% Slope and 100 kg/ha of Applied Nitrogen

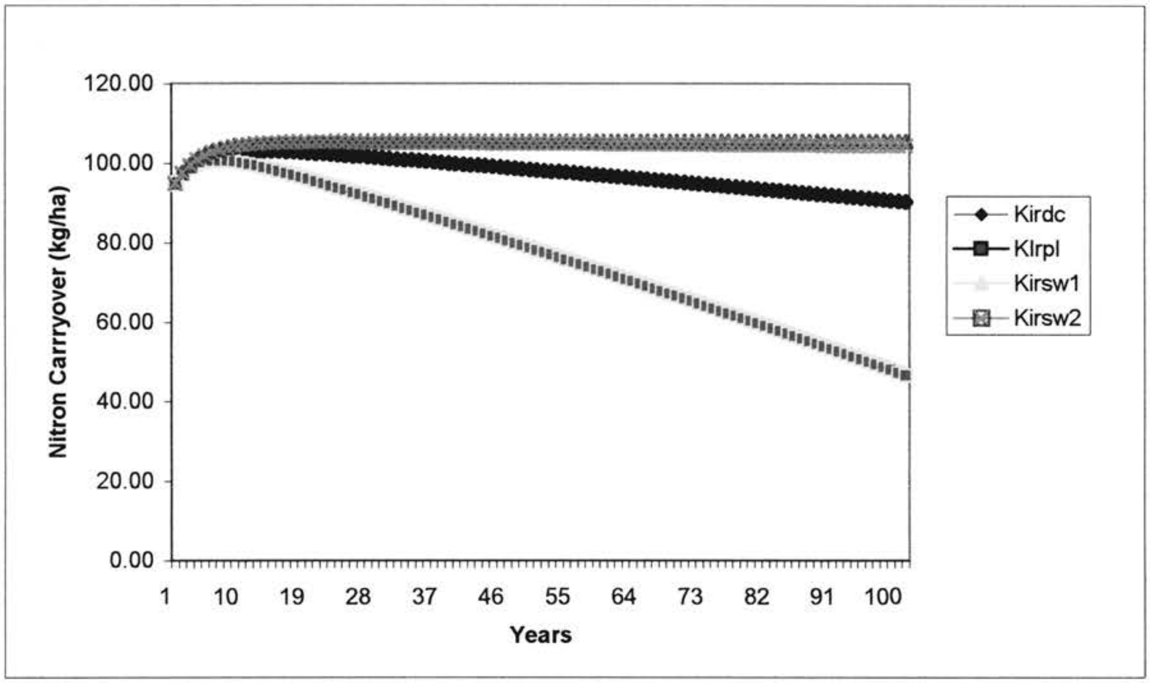
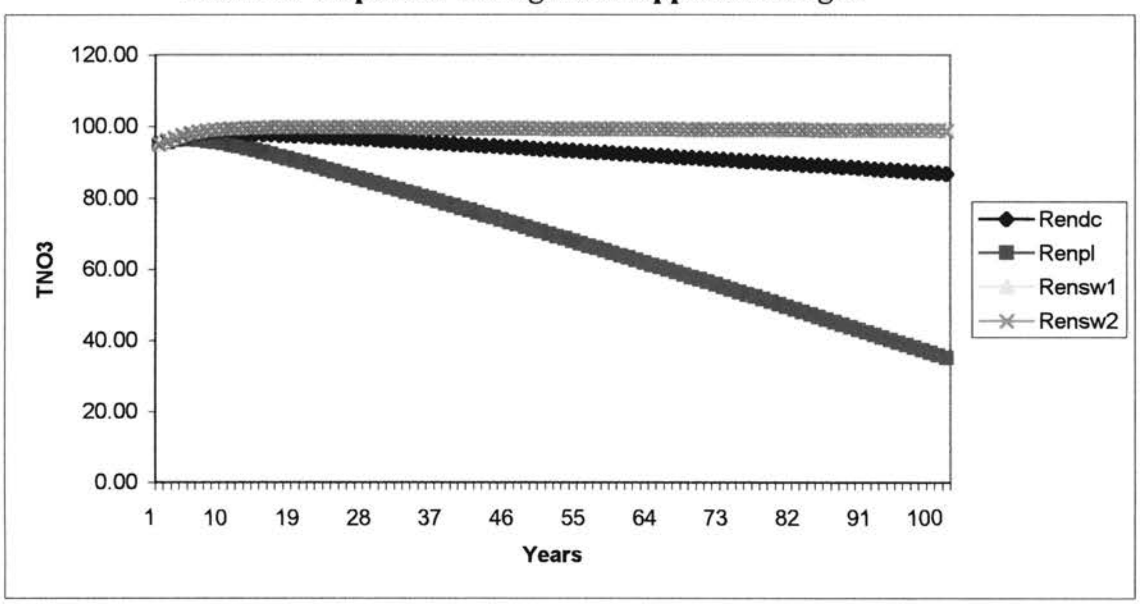


Figure 11. Variation of Nitrogen Carryover per Tillage System on Renfrow Soil With 2% Slope and 100 kg/ha of Applied Nitrogen



respectively, and then decreased to 90 kg/ha and 87 kg/ha, respectively by the end of the planning period.

In summary, the results of the estimation indicates that the rate of nitrogen carryover is higher if conservation tillage systems were used instead of traditional systems despite the fact the estimation was made without a dummy variable for tillage. This difference reflects the change in soil depth as a result of the effect of erosion caused by the use of the particular tillage system.

2. Nitrogen Carryover Function Validation Prior research indicates that nitrogen carryover accumulation depends on soil type and rate of applied nitrogen. However, the accumulation was not correlated with applied nitrogen when the rates were less than or equal to currently recommended rates. Liang et al. (1991) demonstrated that significant amounts of NO3-N accumulated in the soil profile at a high nitrogen rate of 400 kg/ha compared to the recommended rate of 170 kg/ha for irrigated corn over a 3-year period. Schepers et al. (1991) found that groundwater NO3-N concentrations were positively correlated with residual nitrogen in the surface 0.9 m of soil, which reflected past nitrogen and water management practices. Their study concluded that the excess nitrogen application was attributed to producers who exceeded the recommended nitrogen rate of 100 kg/ha.

Research conducted by Westerman et al. (1994) served as a basis for validating the results obtained by this study. The objective of their study as indicated above was to determine long-term response of winter wheat to nitrogen and to evaluate accumulation of NH4-N and NO4-N in soil profile. Four long-term winter wheat fertility experiments were sampled on soil types Kirkland silt loam, Tillman clay loam, and Grant silt loam.

Quadratic equations of total NO3-N accumulation in soil profile, in relation to applied nitrogen were generated for the different experiments. Their experimental results corroborate Liang et al. (1991) and Schepers et al. (1991) findings.

Based on these equations, nitrogen carryover accumulation at the rate of 100 kg/ha of applied nitrogen were 239, 241, 448.5, and 387.3 kg/ha, respectively for Kirkland, Grant, Tillman, and Grant. Two separate studies were conducted at the same location and on the same soil type (Grant). Compared to the estimated results of this study indicated on Table 13, the results of Westerman et al. experiments seem to be very different. However, the experiments also show that nitrogen carryover accumulation is very variable. The difference in nitrogen carryover accumulation among their sampled soils reaches 200 kg/ha when annual nitrogen application rates were 100 kg/ha. Their results show that accumulation of nitrogen carryover varies even within the same soil type. As prior research indicated soil profile and rate of applied nitrogen are responsible for accumulation of residual nitrogen. Among other things, differences in soil depth between the two experiments conducted for Grant soil by Westerman et al. may explain differences in nitrogen carryover accumulation. Nitrogen carryover was 241 kg/ha when soil depth varied from 0 to 2.4 m, and 387.3 kg/ha when soil depth was between 0 and 3 m.

For Kirkland soil type the EPIC simulation assumed a maximum soil depth of 2.02 m. If the maximum soil depth was 2.4, as assumed in Westerman et al. (1994), the predicted average rates of nitrogen carryover on Kirkland soil type in this study would have varied between 115 kg/ha and 140 kg depending on the tillage system used, instead of varying from 98 kg/ha to104 kg/ha. In addition, the maximum rate of applied nitrogen allowed in the EPIC simulation was 150 kg/ha. As Liang et al. (1991) indicated, nitrogen carryover accumulates particularly at high rate of applied nitrogen (400 kg/ha). Thus, in light of EPIC assumptions and the variability of nitrogen carryover, and also considering the fact that the types of soil considered in this study are different from those sampled by Westerman et al. (1994) the apparent low rate of nitrogen carryover obtained by this research seems to be acceptable.

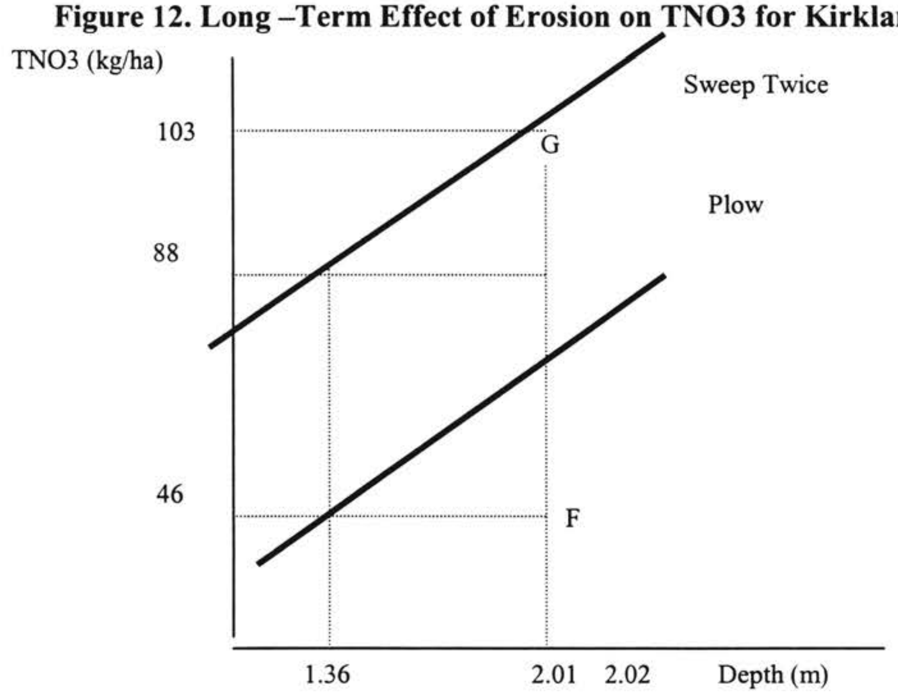
3. Effect of Erosion on Nitrogen Carryover An analysis of the effect of erosion on nitrogen carryover was conducted for each soil type. This analysis is similar to the one performed on the effect of erosion on yield. As indicated above, in both the yield and nitrogen carryover estimated functions, there was no independent variable representing the tillage systems. The differences in nitrogen carryover per tillage system and soil type reflect only differences in soil depth caused by erosion. Table 14 shows the results evaluating the effects of erosion on nitrogen carryover on each soil type when the plow system was used instead of the sweep twice system, assuming 100 kg of applied nitrogen. The results show that there was not much difference in erosion among most soil types. The increase in nitrogen carryover would be reduced between 0.3 kg/ha and 0.6 kg/ha for every inch reduction in soil depth if tillage system plow were used instead of tillage system sweep system twice. The effect of erosion on nitrogen carryover for the Kirkland soil type is illustrated in Figure 12. The distance GF represents the effect of erosion.

Table 14. Effect of Soil Erosion on Nitrogen Carryover per Soil Type[a]

	E D SW2 Meters	TNO3 SW2 K/ha	ED Plow meters	TNO3 Plow kg/ha	TNO3 Diff Kg//ha	Depth Diff Meters	TNO3 Reduction Kg/ha/inch
Kirkland	2.01	103.4	1.36	46.57	14.47	0.65	0.89
Miller	1.51	83.96	0.94	22.99	10.06	0.57	1.09
Norge	1.67	92.14	0.98	33.16	12.15	0.69	0.85
Renfrow	1.89	98.89	1.16	35.02	14.03	0.73	0.87
Vernon	2.01	50.47	1.22	23.42	8.66	0.80	0.33
Zanies	1.51	90.06	0.80	22.91	14.16	0.71	0.94

[a] For detailed explanation of the headings refer to Table 11.

Figure 12. Long –Term Effect of Erosion on TNO3 for Kirkland Soil



Nitrogen Loss Function

The problem inherent in modeling nitrogen loss by soil type is the lack of prior research in determining the functional relationship between nitrogen loss and possible explanatory variables. This is the main reason this study used simulation data for the estimation of the model equations.

Nitrogen loss (surface loss plus nitrogen leached below soil profile) was also estimated in this study as a linear function of soil depth, applied and residual nitrogen, and tillage systems disk chisel, plow, sweep once, and sweep twice. Results of the estimation are shown in Table 14. Numbers in parenthesis are t-values. The coefficients of soil depth and the coefficients of the tillage systems disk chisel, plow and sweep twice system are significantly different from zero for most soils at the 5% significant level for all soil types, while the coefficients of the tillage sweep once system are not significantly different from zero for Miller and Vernon soil types.

The results indicate that the rate of nitrogen application has a very small effect on nitrogen loss. An increase in nitrogen application by one kg will lead to an increase of nitrogen loss by 0.02 kg/ha to 0.04 kg/ha across all soil types, regardless of the type of tillage system used.

Table 15 shows average levels of simulated and predicted nitrogen loss by soil type and tillage system over a 100-year period. The predicted nitrogen loss assumed a constant level of applied nitrogen of 100 kg/ha. The results indicate that conventional tillage systems lead to greater nitrogen losses than conservation tillage systems.

Table 15. Nitrogen Loss Function per Soil Type (kg/ha)

	D Meters	N Kg/ha	DC	PL	SW1	Intercept
Kirkland	46.9016	0.02098	29.75628	105.492	-1.76753	-86.8852
	(6.07)[a]	(4.16)	(26.79)	(32.10)	(-3.74)	(-5.55)
Miller	46.4030	0.01937	32.36047	107.087	-0.15996	-65.2961
	(6.03)	(4.48)	(29.15)	(32.16)	(-0.38)	(-5.60)
Norge	103.380	0.02762	37.79726	117.555	-1.88905	-164.715
	(14.78)	(5.27)	(34.66)	(39.55)	(-3.97)	(-14.07)
Renfrow	61.2473	0.02609	29.92329	98.3477	-1.69660	-108.262
	(9.81)	(5.02)	(31.35)	(36.56)	(-3.53)	(-9.15)
Vernon	21.1923	0.03052	20.85348	56.6499	-0.84455	-35.7721
	(5.50)	(6.63)	(25.35)	(29.49)	(-1.98)	(-4.59)
Zanies	83.0029	0.04588	36.39001	114.384	-1.91524	-117.142
	(12.81)	(7.82)	(33.14)	(41.00)	(-3.51)	(-11.93)

[a] t-values in parenthesis

However, there is a considerable disparity between simulated and predicted nitrogen loss across all soils and tillage system types. The model over estimated nitrogen loss for all soils except when disk chisel was used on Kirkland soils. The over estimation is less systematic when conservation tillage systems are used, but the magnitude of over or under estimation seems to be wider.

Figure 9 and Figure 10 show nitrogen loss over time on Kirkland and Renfrow soils, respectively. The plow system generates much greater nitrogen loss than the other systems followed by the disk chisel system. This is because most of the simulated nitrogen loss occurs with erosion and surface runoff. The conservation tillage systems generate relatively small nitrogen loss. The trend in nitrogen loss for all tillage systems seems to be similar for the two soil types. The question is whether the lower nitrogen loss of the conservation tillage system is enough to compensate their higher cost to make their use more profitable for society.

Table 16 Simulated and Estimated Nitrogen Loss (kg/ha) per Tillage System and Soil Type

	DC		PL		SW1		SW2	
	Simu[a]	Pred[b]	Simu	Pred	Simu	Pred	Simu	Pred
Kirland	37.20	36.10	102.19	100.39	8.53	9.64	10.26	10.17
Miller	36.37	34.27	99.32	100.74	7.26	6.98	8.73	6.66
Norge	41.87	41.20	94.22	93.90	9.71	9.59	10.94	11.31
Renfrow	37.07	35.93	89.39	87.58	8.97	8.75	9.84	10.38
Vernon	29.59	28.72	59.24	58.61	9.55	9.33	10.91	10.19
Zanies	43.66	42.90	99.90	98.72	11.75	11.62	12.43	13.15

[a] Simu=Simulated form EPIC [b] Pred=Predicted by model

Figure 13. Variation of Nitrogen Loss per Tillage System on Kirkland Soil

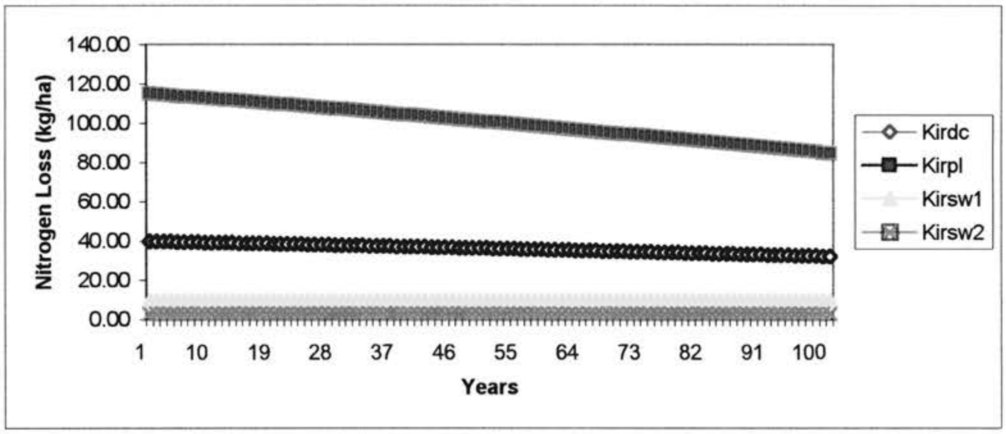
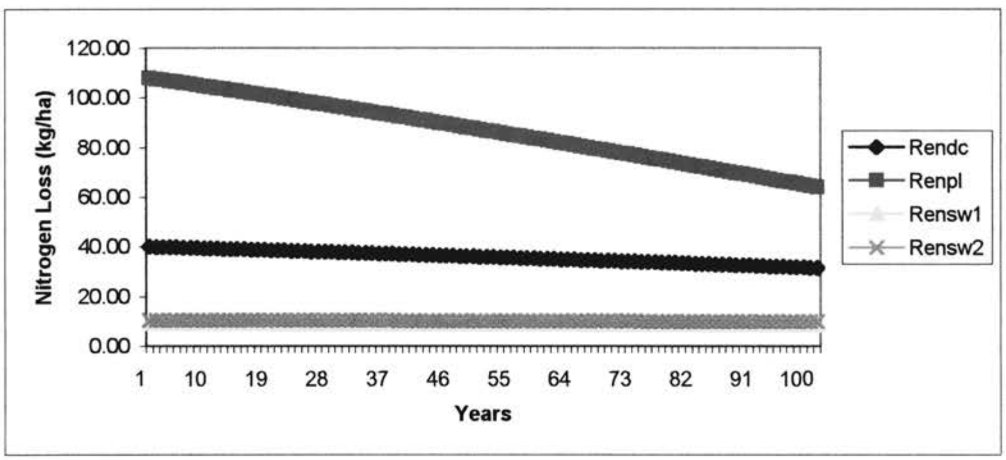


Figure 14 Variation of Nitrogen Loss per Tillage System on Renfrow Soil



Optimization Results

Base Line Solution

The problem faced by the producer in this study is to choose the tillage system and level of nitrogen to maximize the present value of his net returns aggregated across all tillage systems and soil types over a planning period. It was assumed that the farm had six soil types and in each the producer would choose to grow wheat or convert the land to pastures. If wheat were grown, the producer would choose a level of nitrogen and one of the four possible tillage systems. The program was set up for a 100-year period. This is longer than the normal planning horizon but was done to move the end of the planning horizon into a distant future to make the discounted salvage value as small as possible.

The analysis was made at individual soil and farm levels. The farm is defined as a 600-acre wheat and livestock production unit having six different soil types (Kirkland, Miller, Norge, Renfrow, Vernon and Zanies). Four possible tillage operations could be under-taken using disk chisel, plow, sweep once, or sweep twice system. The assumption is that different combinations of soil type and tillage system will generate different rate of soil erosion, with a resulting consequence on long-term yield and offsite damage costs.

The analysis considers both private and social optimums. The private benefit is the present value of net returns to an acre of wheat the producer could expect if he farms 600 acres when only on-farm benefits and costs are taken into account. The returns to land were defined as the total revenue (which varied with remaining soil depth) less the sum of variable costs (applied nitrogen), machinery ownership cost, and property taxes. The social optimum considers in addition to the private costs the offsite damage costs of soil erosion and nitrogen loss. The benefits and costs were valued in terms of 1997 prices. They were determined with and without off-site damage costs. The base solution assumed $3.00 per bushel ($110/MT) for wheat market price of. $0.55/kg for the price of nitrogen, $15000/m/ha for the cost of erosion, $0.35/kg for the cost of nitrogen loss, and 8% discount rate.

Analysis by Soil Type The objective of the analysis was to determine the present value of alternative tillage systems for wheat production in the study area by soil type. It was assumed that the specified tillage system was used throughout the planning period on the particular soil. The net present values are the returns from an acre of wheat the producer could expect if the entire 600-acres of wheat were planted on that soil type.

The average optimum level of applied nitrogen over a 100-year period is presented on Table 17 along with resulting average optimum levels of nitrogen carryover, total nitrogen and nitrogen loss per tillage system, and soil type. The average optimum rates of applied nitrogen are almost identical for the sweep systems, varying between 117 kg/ha and 132 kg/ha across soil types. The rates are slightly higher for disk chisel, varying from 124 kg/ha to 135 kg/ha. The plow system required relatively much higher rates of nitrogen application than the other tillage systems. The corresponding rates were between 136 kg/ha and 147 kg/ha.

Table 17 also shows that average optimum level of nitrogen carryover varies little among tillage system. Thus, total nitrogen, the sum of applied nitrogen, and nitrogen carryover, is generally higher for the plow system. However, the optimum nitrogen available to the plant, that is the remaining nitrogen after deduction of optimum nitrogen loss from total nitrogen, is higher for the sweep systems and disk chisel, than it is for the plow system. This is because the plow system generates more nitrogen loss than the other tillage systems. The optimum nitrogen loss of the plow system varied between 60 and 101 kg/ha whereas nitrogen loss for the sweep system was between 4 and 11 kg/a depending on the soil type.

Thus, the rates of nitrogen available to plants vary form 135 to 227 kg/ha, 112 to 149 kg/ha, 191 to 259 kg/ha, and 190 to 264 kg/ha, for disk chisel, plow system, sweep system once and sweep system twice, respectively depending on the soil type. As indicated above, there was no noticeable difference in yield among tillage systems. However, the yield of the plow system was slightly lower than the yield of the other systems. The difference might be explained by differences in optimum levels of nitrogen available to the plants.

The average net present values of returns to land over a 100-year period are presented on Table 18. When off-site damages were not taken into account, the average net present value of the disk chisel system was higher than the average net present values for the other systems on all soils and the net present value of the sweep once system was the lowest. If the producer were to pay offsite damage costs, the tillage sweep twice system would have the highest net present value on all soil types. The plow system has a negative present value for all soil types. The higher rates of applied nitrogen, higher rates of nitrogen loss, and slightly lower yield was probably the reason the net present value of the plow system was lower than the net present value of the other tillage systems. Considering individual soils, Table 18a and Figures 15 and 16 show that Renfrow soil type has higher net present value than all the other soil types regardless of whether or not the producer was responsible for off-site damage costs.

Table 17. Average Annual Optimum Applied Nitrogen, Nitrogen Carryover, Total Nitrogen, and Nitrogen Loss by Soil Under Alternative Tillage Systems (kg/ha)

Soil	Disk Chisel				Plow System				Sweep System Once				Sweep System Twice			
Type	A N	NC	TN	NL	AN	NC	TN	NL	AN	NC	TN	NL	AN	NC	TN	NL
Kirkland	130	134	264	37	136	118	254	101	130	139	269	10	128	137	265	11
Miller	123	86	209	35	137	76	213	101	117	95	214	7	117	94	213	3
Norge	124	110	239	42	138	102	240	95	122	115	237	10	122	115	237	12
Renfrow	133	133	266	37	143	119	262	88	132	137	269	10	131	137	268	4
Vernon	135	68	203	68	145	64	209	60	131	70	201	10	131	70	201	11
Zanies	131	112	243	44	147	101	248	101	127	117	244	13	127	116	223	14

Abbreviations
AN= Applied Nitrogen, NC= Nitrogen Carryover, TN= Total Nitrogen, NL= Nitrogen Loss

Table 18a. Average Annual Optimum Erosion, Yield, and Net Present Value of Return to Land by Soil Type Under Alternative Tillage Systems

Soil Type	Average Soil Erosion				Average Yield				Net Present Value							
									Without Off-site Cost				With Off-site Cost			
	DC	PL	SW1	SW2	DC	PL	SW1	SW2	DC	PL	SW1	SW2	DC	PL	SW1	SW2
	MT/ha/year				Bushels/acre				Dollars/acre							
Kirkland	2.03	11.06	0.24	0.30	48	43	48	48	748	709	454	569	471	-287	425	526
Miller	1.04	4.39	0.08	0.09	44	42	44	44	643	599	359	472	299	-300	337	441
Norge	3.98	28.37	0.45	0.60	44	44	45	45	635	598	341	456	357	-431	307	413
Renfrow	1.64	9.32	0.25	0.30	49	48	50	50	787	750	493	607	529	-304	455	562
Vernon	4.63	21.43	0.55	0.59	23	22	23	23	-222	-233	-517	-403	-524	-1206	-559	-446
Zanies	3.45	16.31	0.47	0.59	43	43	46	46	661	610	372	486	361	-450	335	432

Abbreviations
AN= Applied Nitrogen, NC= Nitrogen Carryover, TN= Total Nitrogen, NL= Nitrogen Loss

The net present value on Vernon soil was the lowest and negative for all tillage systems with or without offsite damage costs.

Farm Level Analysis The preceding analysis assumed that the 600 acres consisted of one soil type and one tillage system was used throughout the planning period. This analysis assumed that the farm has a mixture of soils. For the farm, there could be a different tillage system every 10years during 50-year period, which is used on all soils. The area of each soil is given on Table 18b.

Wheat production generates most of the revenue. A soil type was converted to pasture in the year after the returns from pasture exceed the returns from wheat production. Pasture becomes economically viable when erosion has reduced wheat yields and annual returns to the point where livestock production was more profitable. Average pasture rent of $8.4 per acre per year was used as a proxy for returns from pasture land. Table 18a gives the results of the optimization at the farm level. It provides the optimum tillage, the average applied nitrogen over 100-year period by soil type, and the optimum net present value. The results show that disk chisel was chosen for each 10-year period when only private costs were relevant. If the farmer was responsible for offsite costs ($1.25/MT of erosion, and $0.35/kg of nitrogen loss), then sweep twice system was the optimum tillage during each investment period. The average private optimum rates of applied nitrogen were less than the socially optimum rates. For the private optimization the rates of nitrogen varied from 125 kg/ha to 135 kg/ha. The corresponding social optimum

Figure 15. Effect of Tillage System on Long Term Returns by Soil Type Without Off-site Cost

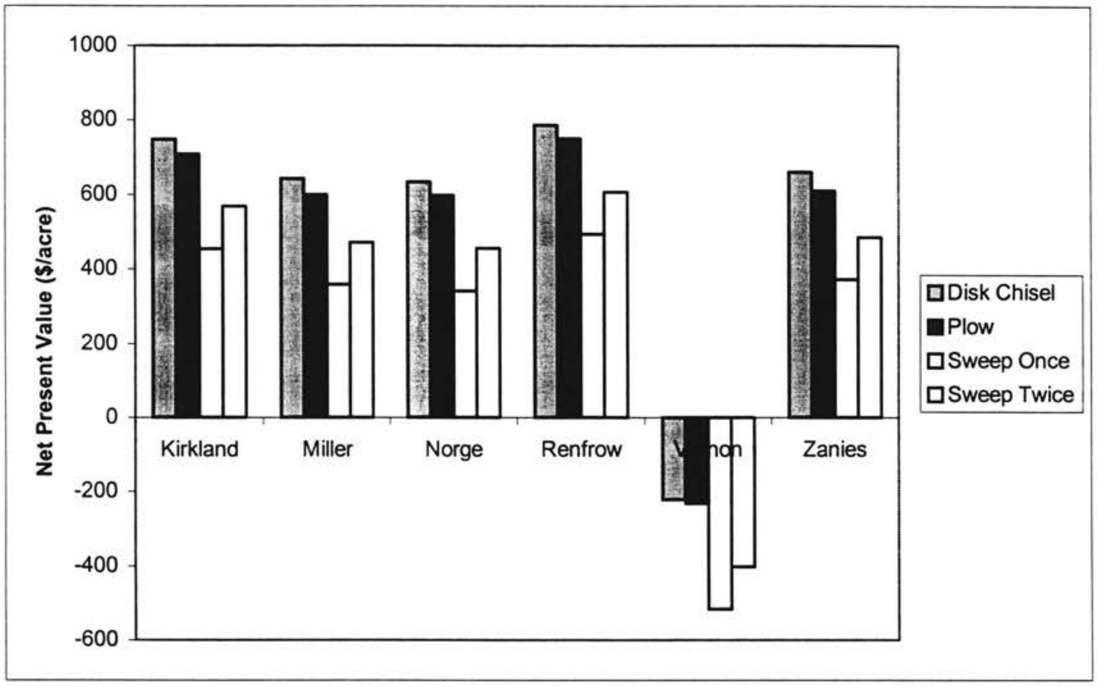


Figure 16. Effect of Tillage System Choice On Long Term Returns by Soil Type With Off- site Costs

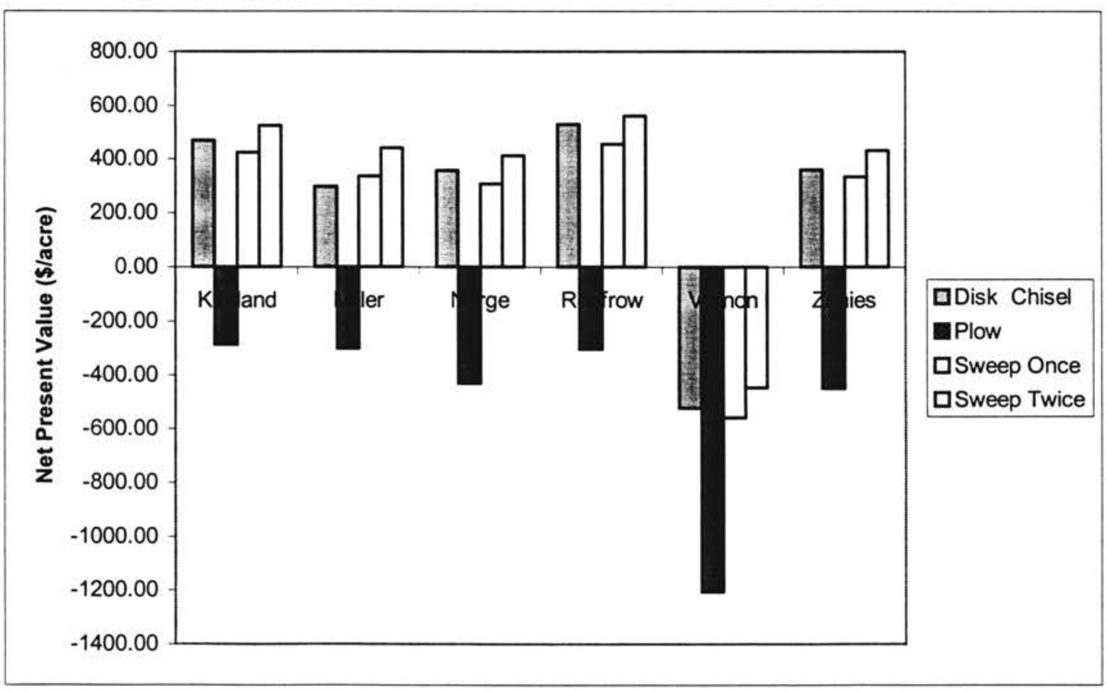


Table 18b. Farm Level Private and Social Optimum Average Applied Nitrogen and Net Present Value

			Private Optimum OT:DC			Social Optimum OT:SW2		
			AN	NPV	TNPV	AN	NPV	TNPV
	Ha	Crop	Kg/ha	$/ha	$	Kg/ha	$/ha	$
Kirkland	88.33	Wheat	131.84	1846.60	163115	129.70	1332.52	117705
Miller	22.08	Wheat	124.76	1588.77	35085	120.54	1105.31	24409
Norge	66.25	Wheat	126.06	1569.22	103960	123.44	1054.63	69869
Renfrow	44.16	Wheat	135.32	1944.38	85876	133.58	1426.83	63018
Vernon	8.83	Pasture	130.40	69.42	613	103.960	30.79	272
Zanies	13.24	Wheat	133.69	1632.89	21636	129.53	1115.65	14782
Farm Level NPV ($)					335563			230226
Farm Level NPV ($/ha)					1381.40			947.77

OT=Optimum Tillage, TNPV=Total Net Present Value

rates were between 121 kg/ha and 133 kg/ha. Wheat was grown on all soils except Vernon series where pasture was more economically viable. Renfrow soils had the highest net present per hectare, but almost 50 percent of the revenues were obtained from the more abundant Kirkland soil type.

Validation of the Optimization

To validate the optimization results, the model was used to calculate the profit a landowner could obtain assuming he has 40% of the revenue, supports 35% of the variable costs, and pays all fixed costs. His profit function would be:

$$0.4 * P_y * Y - 0.35 * P_N * N - FC \qquad (89)$$

where P_y=\$110/MT and P_N – \$0.55/kg are base prices of wheat and nitrogen, respectively, Y and N are optimum levels of wheat and nitrogen, respectively, and FC is annuity payment for fixed costs representing the costs of the tillage systems listed on Table 1. These payments are derived considering 8% discount rate and 10-year investment period. The per acre profit of the landowner per tillage system and soil type is indicated on Table 19. This optimum per acre profit was derived considering only private costs. In general, the conventional tillage systems outperform the conservation systems in case of private optimization. However, the landowner profit is affected to a large extent by the annual machinery, interest, and principal payments that vary considerably from one tillage system to the other. These payments were, \$52.07, \$96.53, \$41.25, and \$41.25 per hectare, for tillage systems disk chisel, plow, sweep once, and sweep twice, respectively. This explains the low landowner income generated from the tillage system plow. If this system is eliminated, the landowner profit will vary from \$22.02 per acre to \$32.37 per acre as indicated on Table 19. The 1997 Oklahoma cropland rental rates published in the Current Report (CR-230-0797) are indicated on Table 20. A comparison of Table 19 and 20 show that each per acre profit of the landowner generated by the model for disk chisel and sweep systems is within the range of the crop cash rental rates prevailing in North Central and East Oklahoma in 1997.

Table 19 Annual Landowner Returns[a] by Tillage System and Soil Type (\$/acre)

	Disk Chisel	Plow	Sweep Once	Sweep Twice
Kirkland	26.58	6.35	31.59	31.52
Miller	22.02	0.53	22.91	27.98
Norge	22.87	2.71	27.79	27.78
Renfrow	24.79	7.73	30.12	32.37
Zanies	23.41	0.74	28.80	28.73

Vernon soil type was ignored, because profit was negative.
[a] Returns to land, management, overhead, and risk

Table 20 State Crop Cash Rental Rates, 1997 (\$/acre)

	Average	Range.	No. of Observations
	Dry land Crops, Grain		
North Central	35.40	25-50	27
East	28.85	10-50	12

Source: Current Report CR-2116-1797 pp 230.2

<u>Substitution of Nitrogen for Soil Depth</u> The use of conservation tillage to decrease soil erosion assumed to imply that this system will use less applied nitrogen than conventional tillage, as a result of smaller decrease in soil depth. This substitution of nitrogen for soil depth from disk chisel to sweep twice is illustrated in Table 21. This table reports the private and social optimum solution for the baseline solution. The results indicate that optimum soil depth for the sweep twice system was higher than the

Table 21. Soil Depth and Applied Nitrogen Comparisons from Private and Social Optimums

Periods	Private Optimum OT :DC					Social Optimum OT:SW2				
	D	N	TNO3	NL	Y	D	N	TNO3	NL	Y
	m	Kg/ha	Kg/ha	Kg/ha	MT/ha	m	Kg/ha	Kg/ha	Kg/ha	MT/ha
0	2.02	141.35	95.00	40.58	3.21	2.020	140.29	95.00	10.80	3.21
10	2.007	130.57	137.56	39.75	3.27	2.018	129.49	137.11	10.52	3.27
20	1.992	123.68	138.53	39.06	3.27	2.017	129.21	138.81	10.46	3.27
30	1.977	131.11	137.72	38.37	3.27	2.016	129.24	138.80	10.41	3.27
40	1.961	131.59	136.85	37.65	3.26	2.025	129.29	138.73	10.35	3.27
50	1.945	132.07	135.86	36.91	3.26	2.014	129.63	138.88	10.30	3.27

D=soil depth, N=nitrogen, TNO3= residual nitrogen, NL= nitrogen loss, Y= yield, OT =optimum tillage optimum soil depth for the disk chisel in each of the 10-year periods. However, the optimum applied nitrogen for the sweep twice system was smaller than the optimum applied nitrogen for the disk chisel for the corresponding periods. Thus, as farmers choose conservation tillage to account for the cost of off-site damages of soil erosion, they will apply decreasing amount of fertilizer and maintain soil depth. The substitution of nitrogen for soil depth reduced nitrogen loss, but had small effect on optimum yield during the 50- year planning period.

Sensitivity Analysis

A sensitivity analysis was performed to determine the effects of changes in discount rates, prices of wheat and nitrogen, costs of nitrogen loss, and erosion on the choice of tillage systems and resulting present values of net returns. The different scenarios considered were outlined previously in Table 2. The sensitivity analysis was made for both private and social optimums. The results are presented on Table 22 through Table 25.

The results show that the optimal choice of tillage system for either private or social optimum is not sensitive to changes in the discount rate, the prices of wheat, and nitrogen prices used in the study. However, the optimal base line solution is sensitive to changes in the cost of erosion and nitrogen loss. For private optimization, disk chisel was the optimum tillage for all levels of discount rates, prices of wheat and nitrogen. Correspondingly, the sweep twice system was the optimum tillage system for the social optimization except when the cost of off-site damages decreased up to $7500/m of soil erosion ($0.75 per ton), and $0.18/kg of nitrogen loss. In this scenario, disk chisel was the social optimum tillage system.

Changing the discount rate from the base scenario to 10 percent and 4 percent, respectively, allowed an analysis of the sensitivity of optimal solution to changes in discount rates. The results are shown in Table 22. In both the private and social optimization, reducing the discount rate to 4 percent increased the net present value per hectare of the overall farm by 85 percent, and increasing the discount rate to 10 percent reduced the net present value per hectare by 20 percent. For the discount rate between four and ten percent, if farmers are not responsible for offsite damage costs they will choose not to use conservation tillage systems. The sweep twice remained the optimal tillage system under the social analysis when the interest rate changed from four to ten percent.

The effects of changes in the price of wheat on the optimal choice and returns of the tillage systems were assessed by considering a 20% change in price. Changes in price of wheat from $110 /MT to $88/MT and from $110/MT to $132/MT had no effect on the choice of the tillage system for either private or social optimization. However, a price decrease by 20% will reduce the net present value per hectare by 40%, and 13% for private and social optimum, respectively. A corresponding increase in the wheat price will increase the net present value per hectare of the farm by 62% and 89%, respectively.

Effects of varying the price of Nitrogen from $0.55/kg to $0.35/kg and from $55/kg to $66/kg were similar to the effect of changes in the wheat price. The disk chisel was always the optimum tillage when the farmer was not concerned by the offsite damages, and sweep twice system was chosen when offsite costs where included. The

Table 22. Effect of Discount Rate on Optimum Tillage

	Area	Discount Rates											
		8%				4%				12%			
		PO OT:DC		SO OT:SW2		PO OT:DC		SO OT:SW2		PO OT:DC		SO OT:SW2	
	Ha	Crop Type	TNPV $	Crop Type	TNPV $	Crop Type	TNPV $	Crop Type	TNPV $	Crop Type	TNPV $	Crop Type	TNPV $
Kirkland	88.33	W	163115	W	117705	W	320695.32	W	234105.91	W	130277.08	W	98764.30
Miller	22.08	W	35085	W	24409	W	67737.80	W	47461.09	W	28179.24	W	18288.45
Norge	66.25	W	103960	W	69869	W	204347.74	W	139175.61	W	83057.41	W	59382.67
Renfrow	44.17	W	85876	W	63018	W	168941.01	W	125486.81	W	68594.19	W	53881.76
Vernon	8.83	P	613	P	272	P	4060.79	P	3359.59	P	1425.53	P	824.63
Zanies	13.25	W	21636	W	14782	W	42332.49	W	29348.32	W	17303.32	W	12181.90
Total	242.91		1381.40		947.77		625852.84		428230.59		274979.76		189466.71
NPV/Ha			1388.44		952.37		2576.43		1766.88		1132.00		779.97

PO = Private Optimum, SO = Social Optimum, OT = Optimum Tillage, TNPV= Total Net Present Value, W=Wheat, P=Past

Table 23. Effect of Product Price on Optimum Tillage

	Area	Product Price											
		$110/MT				$88/MT				$132/MT			
		PO OT:DC		SO OT:SW2		PO OT:DC		SO OT:SW2		PO OT:DC		SO OT:SW2	
		Crop	TNPV	Crop	TNPV	Crop	TNPV	Crop	TNPV	Crop	TNPV	Crop	TNPV
	Ha	Type	$	Type	$	Type	$	Type	$	Type	$	Type	$
Kirkland	88.33	W	163114.96	W	117705.24	W	84715.04	W	39315.12	W	242991.78	W	197581.67
Miller	22.08	W	35532.59	W	24408.85	W	16962.90	W	6260.84	W	53579.87	W	42952.28
Norge	66.25	W	103959.85	W	69869.21	W	49374.25	W	16219.01	W	159629.76	W	125492.54
Renfrow	44.17	W	85876.08	W	63018.06	W	45582.63	W	22756.64	W	126917.94	W	104034.08
Vernon	8.83	P	1875.30	P	1389.74	P	1614.86	P	1130.15	P	2144.24	P	1657.90
Zanies	13.25	W	21635.67	W	14782.26	W	10428.40	W	3202.84	W	33071.96	W	26227.61
Total	242.91		337272.15		231344.15		133955.79		29055.39		543613.24		438116.87
NPV$/Ha			1388.44		952.37		551.45		119.61		2237.87		1803.58

PO = Private Optimum, SO = Social Optimum, OT = Optimum Tillage, TNPV Total Net Present Value, W=Wheat, P=Past

Table 24. Effect of Nitrogen Price on Optimum Tillage

	Area	Nitrogen Price											
		$0.55/kg				$0.44/kg				$0.66/kg			
		PO OT:DC		SO OT:SW2		PO OT:DC		SO OT:SW2		PO OT:DC		SO OT:SW2	
		Crop	TNPV	Crop	TNPV	Crop	TNPV	Crop	TNPV	Crop	TNPV	Crop	TNPV
	Ha	Type	$	Type	$	Type	$	Type	$	Type	$	Type	$
Kirkland	88.33	W	163114.96	W	117705.24	W	180012.33	W	134430.60	W	147694.82	W	102427.09
Miller	22.08	W	35532.59	W	24408.85	W	38974.27	W	28234.94	W	31568.98	W	20946.15
Norge	66.25	W	103959.85	W	69869.21	W	116068.29	W	81818.11	W	92936.32	W	58976.51
Renfrow	44.17	W	85876.08	W	63018.06	W	94565.50	W	71614.26	W	77935.24	W	55151.84
Vernon	8.83	P	1875.30	P	1389.74	P	1968.04	P	1481.53	P	1791.05	P	1306.19
Zanies	13.25	W	21635.67	W	14782.26	W	24192.14	W	17280.23	W	19308.32	W	12503.04
Total	242.91		337272.15		231344.15		381058.27		275030.46		296512.44		191481.61
NPV$/Ha			1388.44		952.37		1568.69		1132.21		1120.64		788.27

PO = Private Optimum, SO = Social Optimum, OT = Optimum Tillage, TNPV= Total Net Present Value, W=Wheat, P=Past

Table 25. Effect of Erosion Cost on Optimum Tillage

		Erosion and Nitrogen Loss Cost							
		$15000/m and $0.35/kg				$7500/m and $0.18/kg		$22500/m and $0.55/kg	
		PO OT:DC		SO OT:SW2		SO OT:DC		SO OT:SW2	
	Ha	Crop Type	TNPV $	Crop Type	TNPV $	Crop Type	TNPV $	Crop Type	TNPV $
Kirkland	88.33	W	163114.96	W	117705.24	W	143149.09	W	114024.21
Miller	22.08	W	35532.59	W	24408.85	W	28862.10	W	23678.11
Norge	66.25	W	103959.85	W	69869.21	W	82104.94	W	67125.25
Renfrow	44.17	W	85876.08	W	63018.06	W	76561.27	W	61148.89
Vernon	8.83	P	1875.30	P	1389.74	P	1423.09	P	1294.09
Zanies	13.25	W	21635.67	W	14782.26	W	18388.43	W	14096.65
Total	242.91		337272.15		231344.15		275766.63		221538.00
NPV$/Ha			1388.44		952.37		1135.24		912.00

PO = Private Optimum, SO = Social Optimum, OT = Optimum Tillage, TNPV= Total Net Present Value, W=Wheat, P=Past

effects of nitrogen price changes on the net present value indicate that a 20 percent reduction in nitrogen price will increase the net present value per hectare of the farm by 13 percent and the social net present value by 19 percent. An increase in the price of nitrogen by 20 percent will reduce the private net present value by 21 percent, and the social net present value by 8 percent.

The choice of the optimal tillage was sensitive to changes in the costs of offsite damages. The initial scenario assumed that the cost of erosion was \$15000/m corresponding to \$1.5/MT of eroded soil, and the cost of nitrogen loss was \$0.35/ kg. The optimal tillage was sweep twice system. An increase in the cost of off-site damages by 50 percent has no effect on the optimal choice of tillage system made in the initial scenario, but when the offsite costs were decreased by 50 percent, disk chisel was optimal under the social analysis. The increase in the offsite damages by 50 percent reduced the net present value per hectare by 4 percent, while the reduction of the offsite costs by the same proportion, increased the net present value by 19 percent.

Summary and Conclusions

Soil erosion constitutes a major problem facing farmers in Oklahoma. Prior research has shown the negative effect of erosion on productivity, and the off-site damages due to air and water pollution (Lyles, 1975, Clark et al., 1985). Research has pointed out the possibility of reducing soil erosion through the adoption of conservation tillage. However, farmers often respond to a yield decrease by increasing the nitrogen application. Not enough work has been done to evaluate the simultaneous effect of adoption of conservation tillage and nitrogen application. Most research was not particularly concerned with the off-site damages resulting from soil erosion and nitrogen leakage.

The objective of this study was to determine if it would be in the long-term interest of the farmer and society to adopt conservation tillage systems for wheat production in Garfield County, Oklahoma when there is a concern about off-site damage of erosion and nitrogen loss. Specific objectives were to:

1. estimate the functions of erosion, yield, nitrogen loss, and residual nitrogen per soil type in relation to the soil depth and type of tillage system used,
2. determine the optimal conservation tillage and rate of fertilizer application for private and social optimization, that maximize expected returns from crop production in the study area,
3. determine the sensitivity of optimal temporal choices to changes in crop, fertilizer, and herbicide prices, discount rates, and value of per unit off-site damages from soil erosion and fertilizer nutrients in surface and ground water.

Chapter 2 first presents the USLE as the tool of choice for soil erosion prediction.

It indicates its improvements through an increase in its flexibility that allows modeling a great variety of systems and alternatives. Next, the chapter presents the impact of erosion on productivity, exposes the difficulty of disaggregating the joint effect of technology and erosion damage, and points out the inherent bias assessment of erosion damage in ignoring technical progress. Then various researches on conservation tillage in the South Plains were described. The results point out the slow acceptance of minimum and no-tillage systems, and the necessity of taking into account other factors including herbicide use, presence of insect and plant disease, soil characteristics, and economic profitability, in the adoption of conservation practices.

In chapter 3 a conceptual framework for solving the erosion problem was developed. First theoretical models of dynamic programming and optimum control models were presented. Then the principles and techniques of these models were applied to models of natural resource use and soil conservation. Based on these procedures, a basic model of this study was developed for both private and social optimization, taking into account the nature of the relationship between the erosion, yield, residual nitrogen, nitrogen loss functions, soil depth, and tillage systems as explanatory variables. The basic model contains two state variables (soil depth and residual nitrogen) and two control variables (applied nitrogen and type of tillage system used).

In chapter 4 the specific methods for solving for the optimal choice of conservation tillage system and optimal nitrogen application were presented. First, an empirical model was developed to take into account the functional forms of the functions of erosion, yield, nitrogen carryover, nitrogen loss, the nature of the equations of motion, the number of soil types and tillage system used, and the length of the planning period.

There were two main sources of required data. The first source was the EPIC simulation data used to estimate through regression analysis the functions of erosion, yield, residual nitrogen and nitrogen loss. The second source was the Oklahoma State University Enterprise Budget Generator used to estimate a budget for each of the four tillage systems used in wheat production. Methods for evaluating the off-site damage costs and choosing discount rates were also presented.

Perhaps the most innovative part of this research was the development and testing of an optimization method. Because of the size of the problem, the presence of integer variables, and the non-linearity, the main concern for solving the model was the likelihood of finding a global solution, the amount of computer memory, and the length of time it would take to obtain the optimal. Further, the sensitivity analysis would require that many solutions be obtained. The search for an optimal solution started with the use of GAMS MINOS solver, but the size of the problem caused many difficulties. The empirical model specified above has more than 2400 linear and non-linear equations and 3620 variables. There are six soil types. For each soil type, each year there are six continuous variables representing the area of wheat and pasture, the soil depth, the rates of applied nitrogen, residual nitrogen, and nitrogen loss (6 X 6 X 100). There are twenty integer variables representing the selection of tillage system machinery in every 10-year period for a 50-year planning horizon. (It is assumed that disk chisel system was used throughout the remaining 50 years). For each year on each soil, the model has four restrictions (area in wheat and pasture, the soil depth, the residual nitrogen, and the nitrogen loss). Thus, the model has 2400 equations (4 restrictions X 6 soil types X 100 years). It also includes five equations representing the machinery selection restriction.

Because of the magnitude of the size of the problem, an optimal solution could not be obtained from the GAMS program.

The solution through dynamic programming also caused many problems because of the infinite number of state variables corresponding to soil depth per tillage system. Given this complexity, the study proposed a branching method through the use of EXCEL software. The method consists of decomposing the optimization problem into a large number of smaller optimization problems. In this process, the problems are solved independently at each soil level. The approach consisted in selecting a sequence of tillage systems over the planning horizon. If the initial soil depth and initial level of soil nitrate are specified, the only remaining variable to determine in each year is the rate of nitrogen application. Thus the smaller optimization problem consisted of finding the optimum level of applied nitrogen that gives the highest net present value obtained for the specified sequence of tillage systems. The specific steps for solving the optimization problem are detailed in this chapter.

Chapter 5 presents the results. The results of the estimation showed that most estimated coefficients were significantly different from zero at the 5 percent significant level and all coefficients have the expected sign.

Despite the simplicity of the erosion function (simple linear function of soil depth), the model was able to make several perfect predictions of the simulated amount of erosion caused by the use of different tillage systems. The trend in the variation of the amount of erosion, similar for all soils showed little change over time, with conventional tillage erosion considerably higher than conservation tillage erosion at.

The average predicted yield confirmed Ellis et al. (1983) that indicated no difference in yield among tillage systems. However, prior research found that conventional tillages had higher yields than reduced tillages (Daniel, Cox and Edwell, 1956, Davidson and Santelmann, 1973, and Harper, 1960). Yield difference was more noticeable among soil types than among tillage systems varying from 3.78 MT/ha to 2.93 MT/ha. Based on data collected from variety trails conducted on farmer fields in North Central Oklahoma, the estimated yields were adjusted to take into account the actual yield of wheat from variety trials in the study area. The resulting yield adjustments did not exceed 25 percent of the estimated yields. Yield variation over time as a result of erosion did show differences in yield among tillage systems. During the 100 years of the simulation period, average estimated yields when applied nitrogen was 100 kg per hectare varied from 3.03 MT/ha to 3.11 MT/ha for the conservation systems and from 3.09 MT/ha to 2.09 MT/ha for plow systems. It was estimated that the erosion effect caused yield to decrease from 9.37kg/ha to 32.96 kg/ha for every centimeter reduction in soil depth depending on the soil type.

The average predicted nitrogen carryover for all tillage systems and soil types were also very close to those calculated from the simulation data. The predicted nitrogen carryover showed no difference among tillage systems. The estimated effect of erosion on residual nitrogen over time was very low, varying from 0.33 kg/ha to 1.09 kg per centimeter reduction on soil depth.

On the opposite, there was a considerable disparity between predicted and simulated nitrogen loss per tillage system and soil type. The model overestimated nitrogen loss levels. The results also show that over time the plow system generates much greater nitrogen loss than the other tillage systems.

It was found that the optimum levels of applied nitrogen were almost identical for the sweep systems varying from 117 kg/ha to 132 kg/ha, depending on the soil type. They were slightly higher for disk chisel, varying from 123 kg/ha to 135 kg /ha. Much higher nitrogen rates were applied for the plow system, from 136 kg/ha to 147 kg/ha.

When off-site damages were not taken into account, the net present value of the disk chisel was higher than the net present value of all the other systems on all soils, and the net present value of the sweep system once was the lowest. If the farmer were to pay off-site damages, the sweep twice system would be the optimal tillage system.

The optimal choice of tillage system and rate of nitrogen application were not sensitive to changes in wheat and nitrogen prices, and discount rates for either private or social optimization. However, the optimal tillage choice was sensitive to changes in the cost of erosion and nitrogen loss. An increase or decrease in the price of wheat or nitrogen price by 20 percent had no effect on the optimal choice of tillage system. Likewise an increase in the discount rate from 8 percent to 10 percent and a decrease to 4 percent did not change the optimal solution. An increase in the erosion and nitrogen loss cost by 50 percent also did not change the optimal tillage choice, but a 50 percent decrease in this off-site cost would shift the optimal tillage system from sweep system twice to disk chisel.

The conclusions of the study are that for private optimization sweep system is the optimal tillage system, and it was not optimum to replace all lost soil by either more nitrogen or other tillage system. For social optimization it would be optimal to use conservation tillage system to maintain both soil materials and soil depth. These results confirm those obtained by Klemme (1983), and Aw Hassan (1992) as indicated in the first chapter. Aw Hassan indicates that disk chisel was the optimum tillage system at all positive discount rates when off-site damages were not taken into account, but this study does consider off-site damages from nitrogen loss. Klemme's results show that that farmers choose no-tillage systems only when soil costs are not assigned.

Limitations of the Study

The data used in this study were generated by the EPIC simulation model. Though the EPIC model attempts to incorporate knowledge gained from previous research in a quantitative and scientific way, the model has certain limitations. Where possible the data study area was used to calibrate the data used in the analysis. However, one serious problem is that there is no way to adjust for the build up of weedy grasses such as cheat, (*Bromus Secalinus*) and insects which reduce wheat yields under conservation tillage. Thus, the conclusions of the study are valid only to the extent that newer herbicides and/or insecticide materials can be found to overcome these problems while creating minimal environmental damage. The study does show there are significant potential gains, which can be obtained from continued research in this area.

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APPENDIX A OKLAHOMA STATE UNIVERSITY ENTERPRISE BUDGET

Table 25 Wheat Dry Land Disk Chisel System

		Unit	Price	Quantity	Value
Operating Costs					$
Wheat Seed		kg	0.18	73.33	13.20
Phosphorus		kg	0.72	46	33.12
Harvesting Cost		$/ha	42.2	1	42.20
Pesticide		$/ha	9.10	1	9.10
Operating Capital		$/ha	8.75% ($43.82)		3.83
Labor, Fuel, Repair					36.72
Total Operating Costs				$ Total	**138.17**
Equipment[a]	Size	Initial Purchase Price ($)	Less Disc Salv Value ($)[b]	Plus PV Tax, Ins ($)[c]	PV of Mach Cost ($)
Tractor	140 HP	49045	7199	4420	46266
Offset Disk	16.1 ft	9500	710	825	9615
Chisel	14.2 ft	4780	357	415	4838
Sweep Con	18.4 ft	10908	815	947	11040
Drill	15.0 ft	12951	967	1125	13108
		84184	10048	7732	**84867**

[a] Equipment required for 243 hectares (600 acres) of crop land

[b] Remaining value after 10 years discounted at eight percent annual interest

[c] Annual value of annual taxes and insurance for ten years capitalized at eight percent annual interest.

Table 26 Wheat Dry land Plow System

		Unit	Price	Quantity	Value
Operating Costs					$
Wheat Seed		kg	0.18	73.35	13.20
Phosphorus		kg	0.72	46	33.12
Harvesting Cost		$/ha	42.2	1	42.20
Pesticide		$/ha	9.10	1	9.10
Operating Capital		$/ha	8.75% ($43.82)		3.83
Labor, Fuel, Repair					41.13
Total Operating Costs		$/ha		$ Total	**142.58**
Equipment[a]	Size	Initial Purchase Price ($)	Less Disc Salv Value ($)[b]	Plus PV Tax, Ins ($)[c]	PV of Mach Cost ($)
Tractor	155 HP	77935	10805	6995	74125
Offset Disk	17.8 ft	14824	1107	1287	15004
M.B. Plow	8.9 ft	13968	1043	1213	14138
Sweep Con	20.4 ft	12928	966	1123	13085
Drill	45.4 ft	40503	3026	3517	40994
		160158	16947	14134	**157346**

[a] Equipment required for 243 hectares (600 acres) of crop land

[b] Remaining value after 10 years discounted at eight percent annual interest

[c] Annual value of annual taxes and insurance for ten years capitalized at eight percent annual interest.

Table 27 Wheat Dry Land Sweep Once System

	Size	Unit	Price	Quantity	Value
Operating Costs					$
Wheat Seed		Kg	0.18	73.35	13.20
Phosphorus		Kg	0.72	46	33.12
Harvesting Cost		Ha	42.2	1	42.20
Pesticide		Ha	84.33	1	84.34
Operating Capital		$	8.75% ($43.82)		3.83
Labor, Fuel, Repair					20.59
Total Operating Costs		$/ha		$Total	**197.28**
Equipment[a]	Size	Initial Purchase Price ($)	Less Disc Salv Value ($)[b]	Plus PV Tax, Ins ($)[c]	PV of Mach Cost ($)
Tractor	95 HP	45830	6345	4113	43590
Sweep Plow	15.5 ft	8100	694	729	8135
Planter	15.0 ft	15435	1380	1450	15505
Total		160158	16947	14134	**67232**

[a] Equipment required for 243 hectares (600 acres) of crop land

[b] Remaining value after 10 years discounted at eight percent annual interest

[c] Annual value of annual taxes and insurance for ten years capitalized at eight percent annual interest.

Table 28 Wheat Dry land Sweep Twice System

		Unit	Price	Quantity	Value
Operating Costs					$
Wheat Seed		Kg	0.18	73.35	13.20
Phosphorus		Kg	0.72	46	33.12
Harvesting Cost		Ha	42.2	1	42.20
Pesticide		Ha	61.70	1	61.70
Operating Capital		$	8.75% ($43.82)		3.83
Labor, Fuel, Repair					20.62
Total Operating Costs		$/ha		$ Total	**174.67**
Equipment[a]	Size	Initial Purchase Price ($)	Less Disc Salv Value ($)[b]	Plus PV Tax, Ins ($)[c]	PV of Mach Cost ($)
Tractor	95 HP	45830.00	6345.00	4113.00	43590
Sweep Plow	15.5 ft	8100.00	694.00	729.00	8135
Planter	15.0 ft	15435.00	1380.00	1450.00	15505
Total		160158.00	16947.00	14134.00	**67232**

[a] Equipment required for 243 hectares (600 acres) of crop land

[b] Remaining value after 10 years discounted at eight percent annual interest

[c] Annual value of annual taxes and insurance for ten years capitalized at eight percent annual interest.

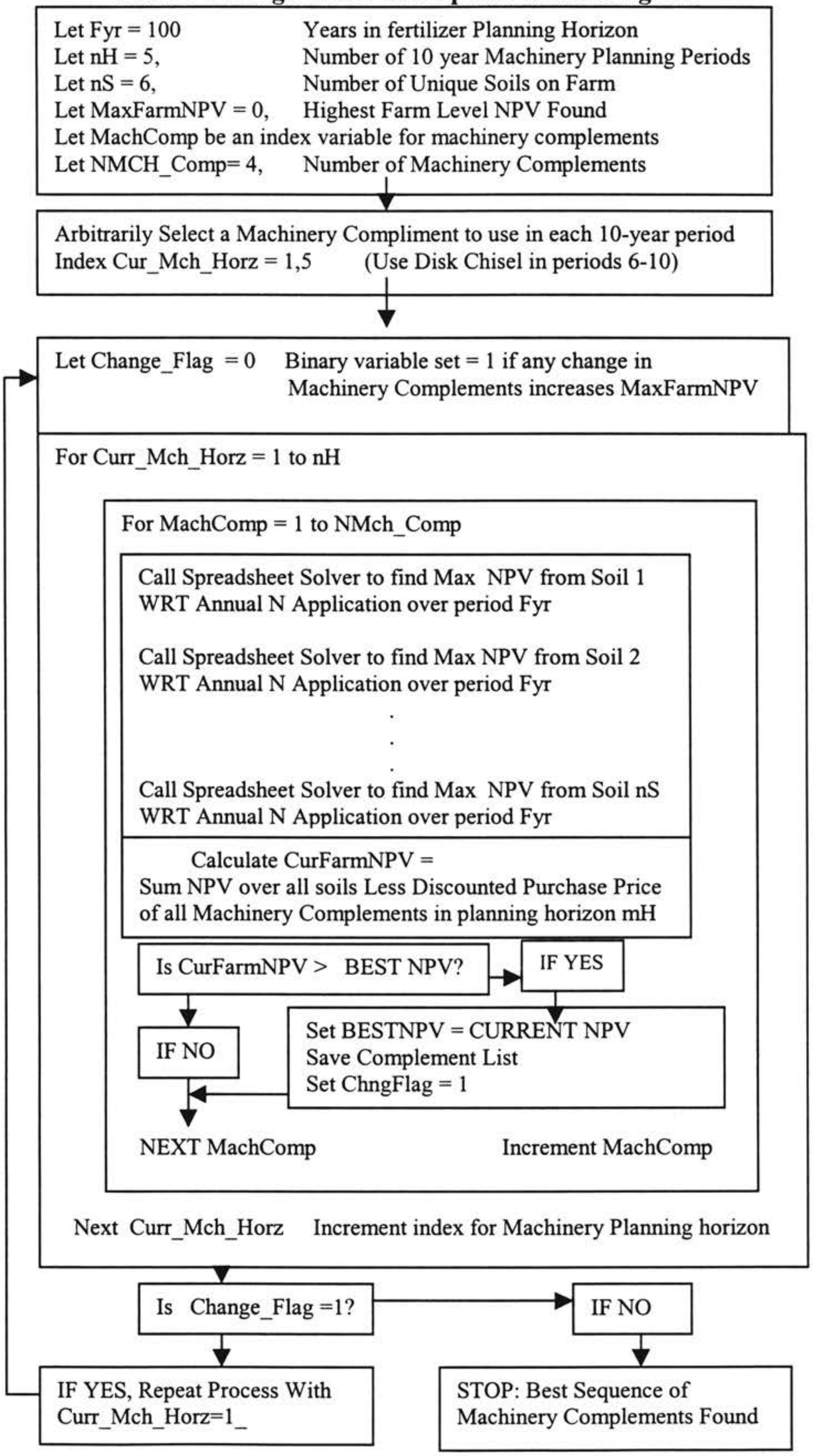
APPENDIX B

Table 29. Erosion Conversion Factors by Tillage System and Soil Type [a]

Soil Types	Tillage Systems			
	Disk Chisel	Plow	Sweep Once	Sweep Twice
Kirkland	0.000803	0.000589	0.000200	0.000371
Miller	0.000055	0.00127	0.000181	0.000999
Norge	0.000391	0.000242	0.000111	0.000140
Renfrow	0.000854	0.000779	0.000363	0.000381
Vernon	0.000503	0.000367	0.000232	0.000181
Zanies	0.000465	0.000432	0.000019	0.000194

[a] Conversion from MT/ha to linear meter

Annex C Diagram for the Optimization Program



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