Evaluating Effects of Tillage on Soil Erosion and Future Agricultural Productivity

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EVALUATING EFFECTS OF TILLAGE ON SOIL EROSION AND FUTURE AGRICULTURAL PRODUCTIVITY

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CONTENTS

TABLES

FIGURES

EVALUATING EFFECTS OF TILLAGE ON SOIL EROSION AND FUTURE AGRICULTURAL PRODUCTIVITY

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INTRODUCTION

Croplands in the United States are among the most fertile in the world. An important factor contributing to the fertility of these croplands is their rich topsoil. Conventional cropping systems often result in excessive erosion of topsoil and eventually result in lost productive capacity. This loss in soil productivity has been successfully masked by the introduction of genetically improved plants, increased application of fertilizer, and the introduction of improved agricultural chemicals for pest control.

The fact, however, remains that the basic productivity of the land resource is being eroded away. Yield levels on highly eroded areas of the dry cropland regions of Oregon and other Northwest states are significantly reduced over the deeper soils.

Current United States Department of Agriculture, Soil Conservation Service efforts in the Camas Prairie of North Central Idaho provides a data source that allows examination of the long-term productivity effects of erosion. Societies' benefit from this analysis is an improved estimate of the benefits associated with controlling erosion on agricultural lands. Economic evaluation of land treatment by SCS and several states guides the allocation of scarce public resources designated for erosion control. Long-term productivity is an important consideration in setting priorities for funding land treatment projects. Fragile soils respond more quickly to lost productivity through erosion and, therefore, have a higher economic return to erosion control efforts.

The search for a method of measuring long-term consequences of soil erosion on agricultural soil productivity has generated a considerable body of literature. In a 1928 USDA circular, Bennett and Chapline argued that uncontrolled erosion would drastically reduce crop yields and threaten the nation's ability to fill our food and fiber needs (Jackson 1980). Pawson, in a study of The Palouse, speculated that topsoil productivity could be maintained despite erosion, by substituting nitrogen fertilizer for topsoil (Pawson 1961). Others have analyzed the impact of erosion on productivity through the years. In 1979, Thomas and associates addressed the effects of technological change on yield. They introduced a method to, "... isolate the impact of soil losses on yield from technological changes that improve productivity" (Thomas et al., 1974).

Development of a methodology to assess the impact of erosion on long-term productivity requires many intellectual contributions. As each analyst views the problem, he is faced with the need to solve a conceptual problem that was not resolved by his predecessors. Such is the case in this paper; the intent is to review a method developed by Dr. D. B. Taylor (Taylor, 1982) and determine if it can be applied to other regions in the Northwest, or if a modification in the treatment of cost would improve its empirical accuracy and solidify its theoretical basis.

The Idaho region was chosen for study because of the concentrated USDA effort and the availability of quality data. USDA's Soil Conservation Service, Economic Research Service, and Forest Service are cooperating with the Idaho Department of Water Resources in a land treatment river basin study on the Camas Prairie near Nez Perce, Idaho.

Taylor developed a model for evaluating various soil conserving techniques (Taylor, 1982). He incorporated technology change into the model as a multiplicative factor and estimated a nonlinear topsoil-yield response function. The Taylor model calculates discounted net farm income for an individual farmer using a specific tillage system. Several criticisms have been made against the Taylor model. This report, based on Bauer (1984), identifies the assumptions, implicit and explicit, of the Taylor model. They, along with its parameters and functional relationships, are reviewed and evaluated for the purpose of improving the accuracy of the model.

The specific objectives include:

1. Review and refinement of the soil-productivity loss model developed by Taylor.
2. Comparison of the income estimates of the original Taylor model and of the refined model.
3. Estimation and comparison of income streams of conventional tillage, reduced tillage, and no-till using the refined model for the Camas Prairie Region of Northern Idaho.

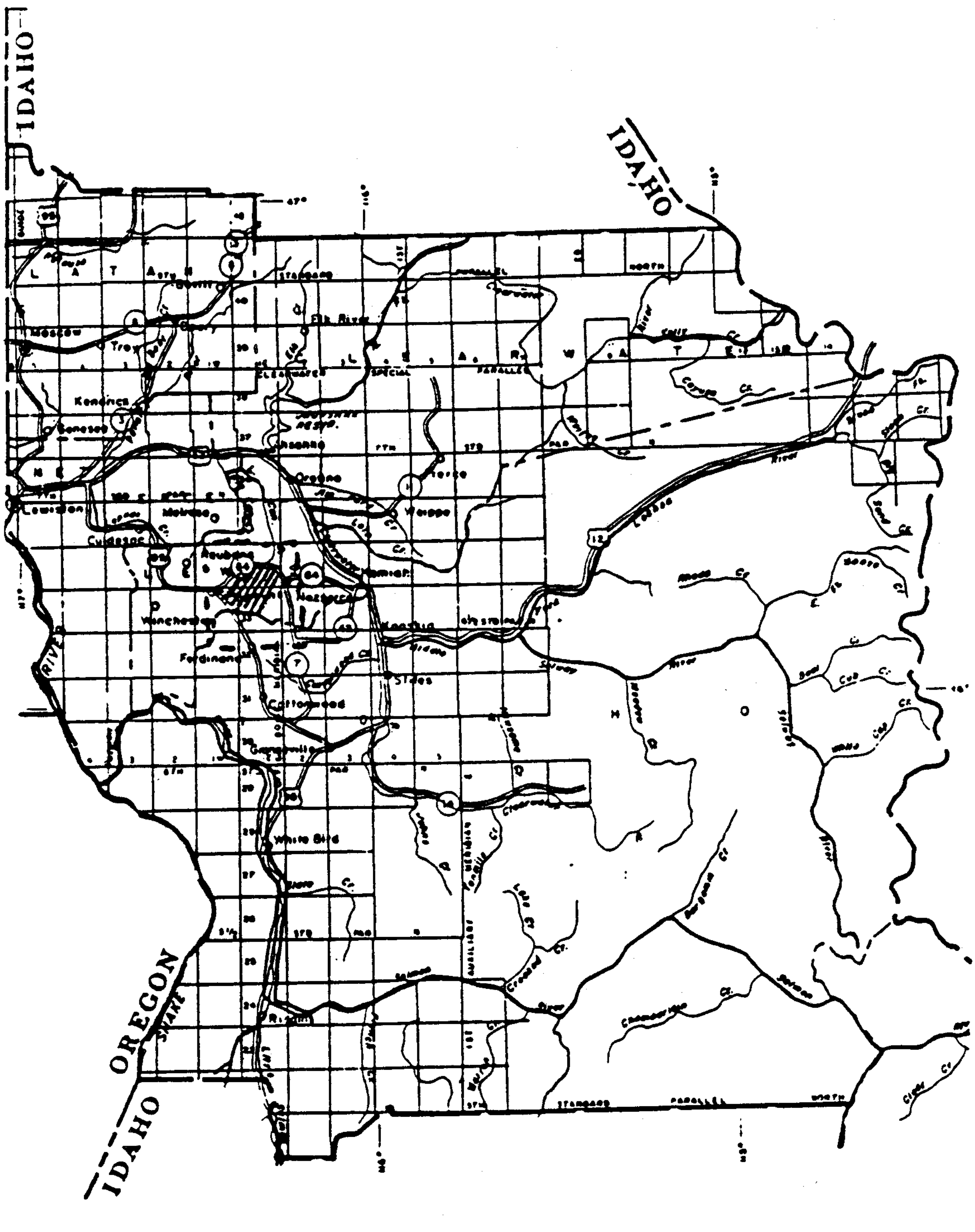
STUDY AREA

The study area is the Camas Prairie Region of Northern Idaho. As illustrated in Figure 1, it is in Lewis, Idaho, and Nez Perce counties and includes about 240,000 acres. The Camas Prairie extends for about 30 miles north to south and 25 miles east to west (Fisher, 1938). It is underlain by Columbia River basal flows and the rolling plain topography was formed by the warping of this basal. The original vegetation of the area was short-grass prairie (Ross and Savage, 1967).

The majority of the watershed is comprised of the typical rolling hill topography of the Camas Prairie. About 15,500 acres of the watershed is cropland with winter wheat, the principal crop, followed by spring barley and Austrian winter peas. Lentils, green peas, and blue grass are secondary crops grown in the area. Precipitation averages 21 inches per year. Temperatures are moderate, rarely exceeding 90 degrees Fahrenheit in the summer or dropping below 0 degrees Fahrenheit in the winter.

Erosion Problems of the Study Area

About one-half of the cropland in Lewis County is experiencing erosion rates in excess of five tons per acre per year, with some acreage experiencing erosion of more than 26 tons per acre per year (USDA, 1982). In the spring, localized intense rain storms occasionally occur causing severe erosion (Golden, 1983).



//// Long-Hollow Creek
Watershed.

SOURCE: (USDA 1981)

Figure 1. Location of the Camas Prairie in Idaho.

The formation of topsoil from the basaltic subsoil is a relatively slow process. Scientists estimate that an inch of topsoil can be formed every 100 to 1000 years under agricultural conditions (Pimental et al., 1976). Using the fastest rate of soil formation, soil is forming at a rate of 1.45 tons per acre per year. Since soil depths in the area are 18 to 22 inches, it is apparent that soil mining will have serious long-term productivity consequences.

Tillage Methods

Soil tillage practices have different costs, and may result in different crop yields and erosion rates. Farmers of the Camas Prairie region use a wide variety of tillage implements and systems. This study will focus on three tillage systems which span the spectrum of the tillage systems used on the Camas Prairie.

The three tillage systems are conventional tillage, reduced tillage, and no-till. The first system, conventional or heavy-tillage, is a typical inversion tillage system. It uses a moldboard plow to invert and cover crop residues. The second system, reduced-tillage, is an example of a noninversion conservation tillage system. This system retains a crop residue on the surface to protect the soil from erosion. In the third system, no-till, the crop is planted directly into the untilled soil. It, therefore, minimizes the disturbance of the soil.

REVIEW OF THE TAYLOR MODEL

Measuring Soil Loss

Soil loss in the Taylor model is estimated from the Universal Soil Loss Equation (USLE). The unit of soil loss used in the Taylor model is inches per acre. The USLE erosion estimate, in tons per acre, is converted to inches per acre by the following equation:

(1) $Q_s = A/W.$

Where:

Q_s = soil loss in inches per acre;

A = soil loss calculated in tons per acre by the USLE;

W = weight of an acre inch of soil.

Yield-Topsoil Depth Function

The effects of soil erosion are manifest in loss of crop yields. If the effects of soil loss are to be quantified, a relationship between soil loss and crop yields must be developed. Crop yields are a function of all the factors affecting the growth of the crops in that year (Taylor, 1982). Other factors such as those which affect the maturation and harvest of the crop also influence the yield. This relationship could be reflected in a production function such as:

(2) $Y_{Dt} = f(D_t, P_t, M_t, C_t, X_t, t_e).$

Where:

Y_{Dt} = crop yield per acre at time t;

f = a functional operator;

D_t = topsoil depth in year t;

P_t = physical characteristics of the site including soil and topography;

M_t = management factors in year t, such as tillage methods, fertilization, weed control and harvest methods;

C_t = weather factors in year t, such as rainfall and temperature;

X_t = other factors which influence yield in year t;

t = year index;

t_e = the given technology of the time period for which the production function is valid.

Data limitations led Taylor to simplify the above production function to the following function:

(3) $Y_{Dt} = f(D_t, P_t, M_t, C_t, X_t, t_e)$.

This function can then be further simplified to:

(4) $Y_{Dt} = f(D_t)$

This simplification is not as drastic as it appears. A strong relationship exists between topsoil depth, D_t, and the soil physical factors, P_t (Walker and Young, 1981). Topsoil depth has been found to be highly correlated with soil type, percent slope, length of slope, and direction of slope or aspect (Pawson et al., 1961). Shallower soils generally are less desirable for plant growth than deeper soil. Poor plant growth results in poor yields, therefore, a relationship between topsoil depth and crop yield exists (Pawson et al., 1961; Stallings, 1957). This relationship makes topsoil depth a relatively good proxy for the properties of the soil.

Previous studies have assumed a linear relationship between topsoil depth and yields (Krauss, 1979). A linear relationship reflects constant returns to topsoil depth. Such a relationship implies that yields will increase indefinitely with increases in topsoil depth, which is not consistent with the law of diminishing returns and with the limitations of rooting depth of crops (Taylor, 1982). A linear function, therefore, is inappropriate. An appropriate function must exhibit diminishing returns to topsoil depth. A function with a maximum also is not appropriate. Rather the curve should approach asymptomatically a maximum yield value. The yield value/soil depth relationship should vary as soil characteristics change.

The Taylor 1982 model incorporates diminishing marginal returns to topsoil depth while maintaining a positive marginal product by using an asymptotic functional form, (Figure 2). The function, referred to as a Mitscherlich-Spillman function, (Spillman and Lang, 1924) takes the following form:

(5) $Y = M - AR^{x}$.

Where:

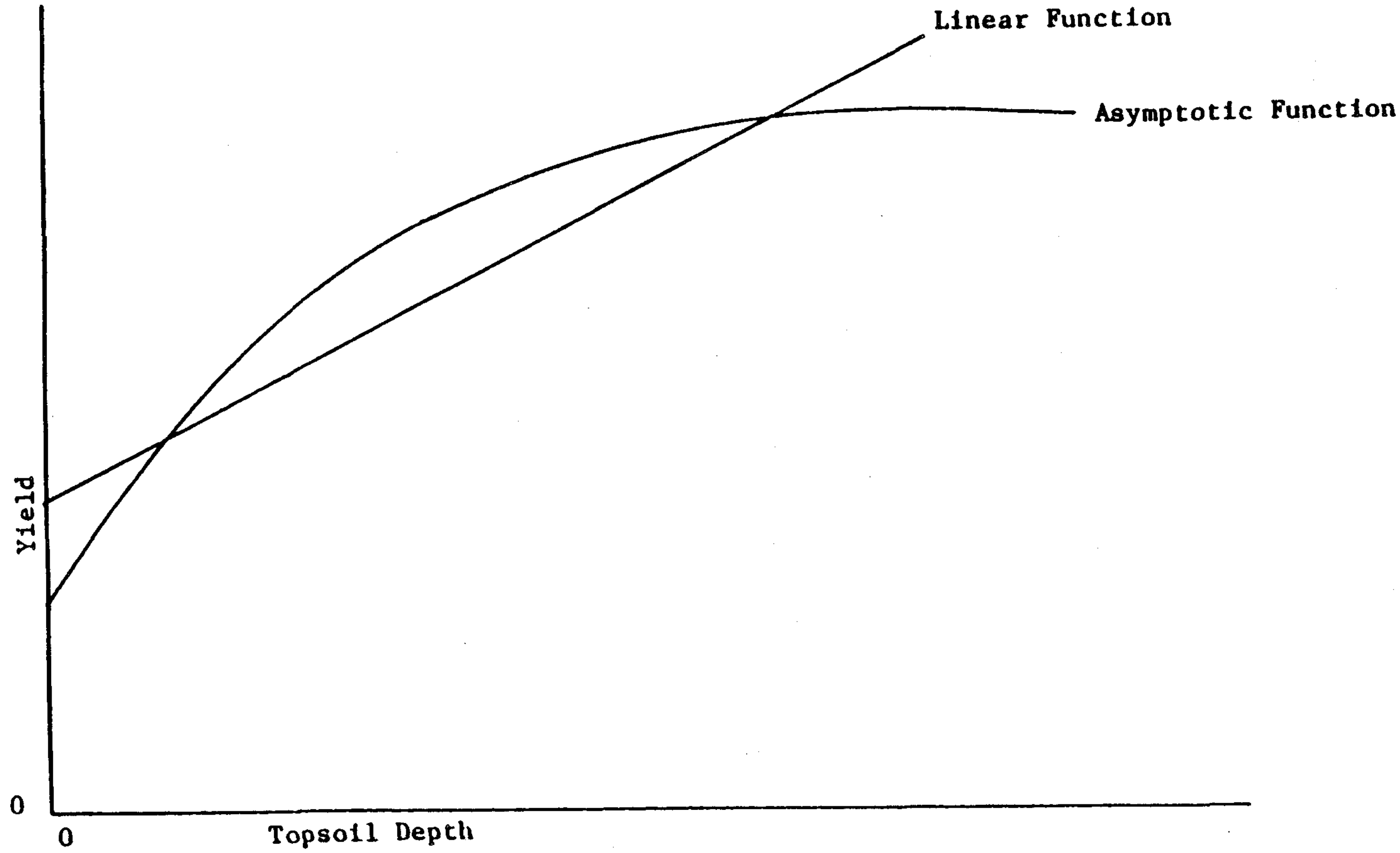
Y = the crop yield;

M = the theoretical maximum yield obtainable through additional units of input x;

A = the sum of the declining geometric yield increment series to infinity;

R = the constant ratio between consecutive terms of the declining geometric yield increment series;

x = the level of input.



SOURCE: (Taylor 1982)

Figure 2.

The Spillman-Mitscherlich functional form used in the Taylor model and in this study is:

(6) $Y_{Dt} = a + b(1 - R^{D}t)$.

Where:

a = the intercept term which represents crop yield at zero topsoil depth or on subsoils;

b = the maximum increase above subsoil yields that can be obtained on infinitely deep topsoils (A of equation 5);

a + b = M of equation 5;

$(1 - R^{D}t)$ = the proportion of the maximum yield increase, b, attained at topsoil depth D_t;

$b(1 - R^{D}t)$ = the amount of the maximum yield increase, b, attained at topsoil depth D_t;

R = (marginal product of the ($D^{\underline{th}}$ + 1) inch of topsoil)/ (marginal product of the $D^{\underline{th}}$ inch of topsoil);

D_t = the topsoil depth in inches at time t;

t = a time index, with t = 0 being the start of an analysis period; t = 0, 1, ..., n years.

The use of equation 6 implies that once zero topsoil depth is reached, yields will remain constant at the subsoil level, regardless of further erosion. Since this assumption is probably not a realistic assumption, the use of equation 6 is valid only in analyses in which the topsoil is never completely eroded away.

The topsoil depth in year t, D_t, is calculated as follows:

(7) $D_t = (D_o - Q_{st})$.

Where:

D_o = topsoil depth in inches at t = 0, the start of the study period;

Q_s = average annual soil loss in inches for the site.

Replacing topsoil depth, D_t, with the erosion determined depth, $(D_o - Q_{st})$, results in the following specification of the yield-topsoil depth equation developed by Taylor (1982) and used in this study:

(8) $Y_{Dt} = a + b\ (1 - R^{(D_o - Q_{st})})$.

All terms of the equation are those previously defined.

The Yield-Technological Progress Relationship

Another critical relationship which must be included in a realistic soil-productivity loss model is the effect of technological change on yield. Technological progress has not rectified the productivity loss caused by erosion, although it may have masked its observable effects by increasing yields. Crop yields have increased despite erosion through technological advances brought about by high yielding hybrid crop varieties, chemical fertilizers, pesticides, and improved tillage practices. Cropland production has increased, but cropland productivity may have declined. If erosion had not occurred, crop yields may have been higher. The lost soil productivity from erosion, therefore, should be measured as the difference between the potential crop yields which could have been attained with no erosion and the actual crop yields produced in the presence of erosion.

If technology increases yields more on deep topsoils than on shallow topsoils, projections of soil productivity loss that exclude technological change underestimate this loss. If, however, technological progress increases yields by an equal amount regardless of topsoil depth, projections of soil productivity loss could exclude technological progress. Technological change would then be independent of topsoil depth. Empirical work has supported the former relationship (Young, Hoag, Taylor, 1982). Empirically this relationship can be represented in the following multiplicative form:

(9) $Y_t = Y_{t-1} * (1 + k)$.

Where:

Y_t = yield in year t;

Y_{t-1} = yield in year t-1;

k = a positive constant representing the percentage yield is increased each year.

Figure 3 shows a positive, multiplicative yield-technological progress relationship having the characteristic that technological change increases yields more on deep topsoil than on shallows topsoil. The Taylor model uses the following functional form of the multiplicative yield-technological progress relationship. It is absent of erosion:

(10) $Y_t = B_o * e^{Bt}$.

Where:

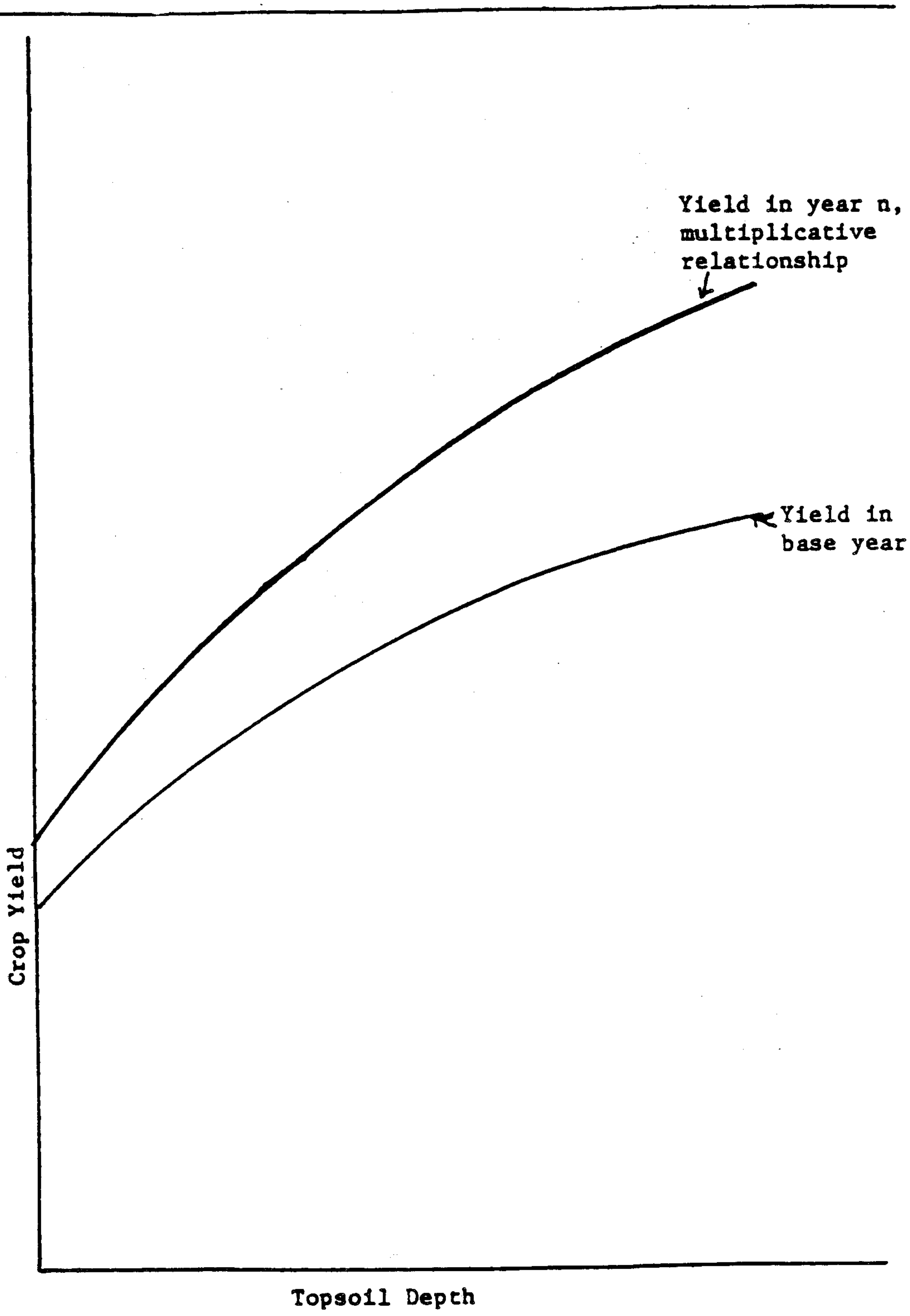
Y_t = yield in year t;

B_o = the intercept term or initial year yields of the function;

e = the exponential operator;

B = slope parameter of the function or the percentage yield is increased each year by technological change;

t = time period.



SOURCE: (Young et al., 1982)

Figure 3. The Effects of a Positive Multiplicative Yield-Technological Progress Relationship on Crop Yields.

Combining this relationship with the topsoil-yield response function results in the following function:

(11) $Y_{Dt} = a + b(1 - R^{(D_o - Q_{st})})\ e^{Bt}$.

All terms have been previously defined.

Tillage-Yield Effects

Tillage systems also can affect crop yields. The tillage-yield effects of less intensive tillage systems have not been conclusively determined. It has been argued that conservation tillage systems can increase, decrease, or not change yields relative to intensive tillage (Harder, Peterson, and Dowding, 1980; McCool, 1983). Climate, soil, tillage operations, and other factors in combination determine the tillage yield-effect. Harder et al. (1980), in a study in northern Idaho, found that continuous conservation tillage systems depress yields relative to conventional tillage systems. Michaelson et al. (1983) reported large yield penalties associated with conservation tillage. The tillage-yield effects used in this study are those of Harder et al. (1980) which used data collected in northern Idaho under climatic conditions most similar to those of the Camas Prairie.

The completed agronomic submodel takes the following form:

(12) $Y_{Dt} = a + b(1-R^{(D_o - Q_{st})})\ T_s(e^{Bt})$.

Where:

T_s = multiplicative tillage yield effect.

All other terms have been previously defined.

ECONOMIC SUBMODEL

Taylor's basic unit of analysis is the study site. All study sites combined comprise the study area. For example, a farm could be the study area and the study sites could be fields, or a field could be a study area and the study sites could be land classes. The Taylor model calculates topsoil loss, crop yields, and discounted before-tax net income for each study site over a 100-year simulated period. These values are then added over the entire study area for study area statistics. Figure 4 outlines the structure of the model. The study area in this paper is a representative Camas Prairie farm of 600 acres. The study sites are land areas defined by slope within the farm.

Variable Costs

Variable costs of production include all the costs of planting and harvesting, including pesticides, fertilizer, fuel, and repair costs of the equipment, hired labor, and interest on operating capital. Variable costs per acre are assumed to remain constant throughout the length of the analyses.

Fixed Costs

Fixed costs in the original Taylor model are depreciation and the opportunity cost of the average capital investment. The fixed costs are based on the total value of the machinery complement. These components remain constant and are incorporated into the model by the following equation:

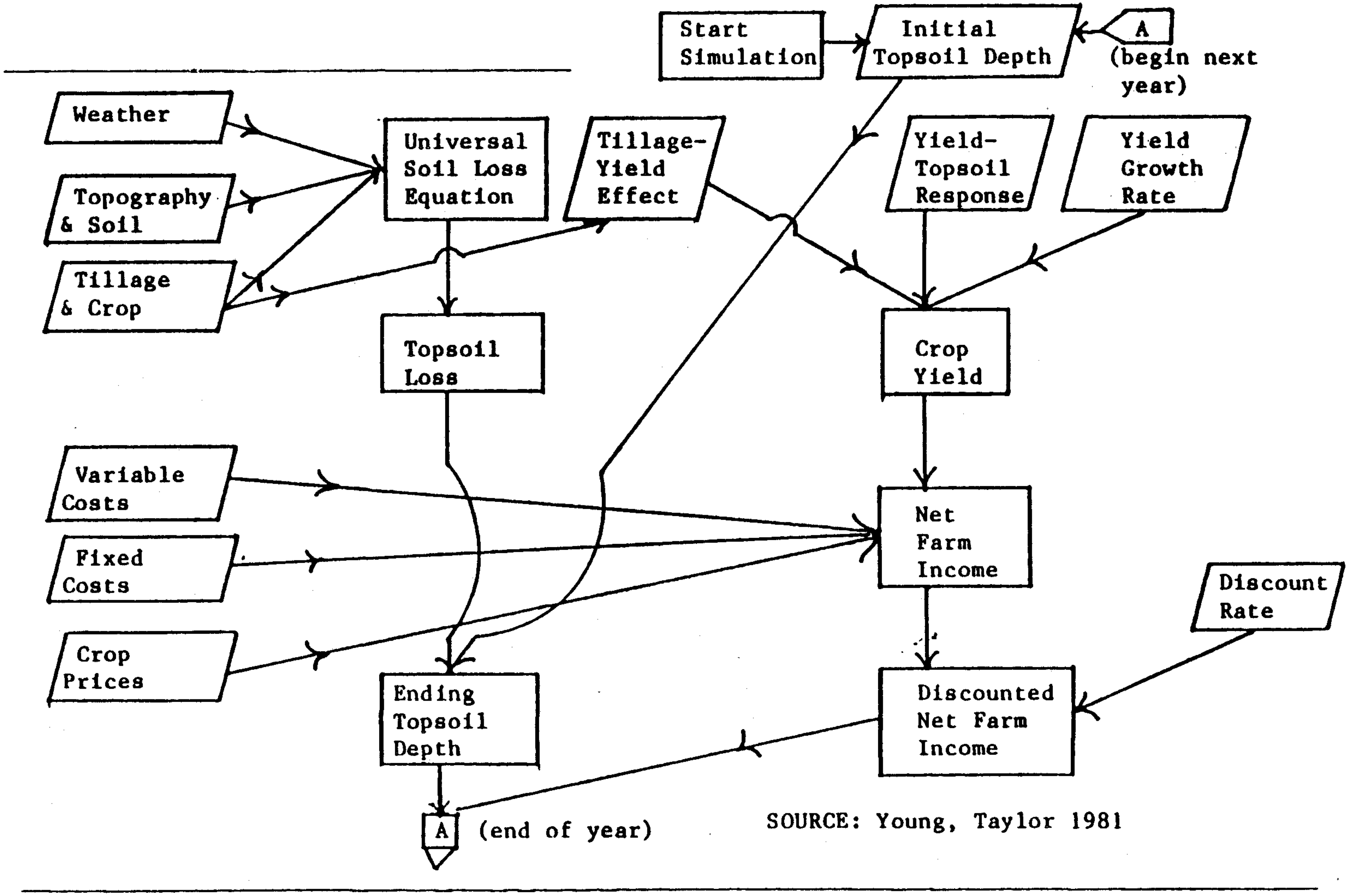


Figure 4. Taylor Model Structure for a Study Site.

(13) $FC = DC + OC.$

Where:

DC = depreciation;

OC = opportunity cost of capital investment.

The simulation model uses straightline depreciation and assumed the machinery has a 10-year life with zero salvage value. Machinery investment, MI, represents the total purchase price of the machinery complement. Annual depreciation, DC, is calculated as follows:

(14) $DC = MI * 0.10$

Annual opportunity cost of capital represents returns which could be realized if capital invested in machinery were in an alternative investment. This cost is based on the average value of the capital tied up in the machinery over the length of the simulation. It is calculated as follows:

(15) $OC = (MI/2) * MIR.$

Where:

MIR = the interest rate available to the farmer in alternative investments.

Farm Income

Gross receipts for a specific crop are defined as the crop yield multiplied by a five-year, weighted average crop price. Gross farm income is the summation of all gross receipts. Before-tax net farm income is calculated as returns to land, operator and unpaid family labor, overhead, and management. Farm real estate taxes and the opportunity cost of capital invested in land (rent) are not included as costs. Hired harvest labor is included, but labor provided by the farm operator is not. The cost of buildings, storage facilities, and other miscellaneous production inputs and a management charge also are not included as costs.

Discounted before-tax net farm income is computed as follows:

(16) $NI_t = (GI_t - VC - FC)/(1 + i)^t$.

Where:

NI_t = net before-tax income in year t, discounted to the starting year of the simulation;

GI_t = gross income in year t;

VC = variable costs;

FC = fixed costs;

i = the real discount rate;

t = 0, 1, 2, ..., n.

Costs, prices, gross returns, and profits are measured in constant base year dollars. The discount rate, i, represents real, inflation-free interest.

CRITIQUE OF MODEL

The Yield-Technological Progress Function

The yield-technological progress function of the Taylor model is:

(17) $Y_t = B_o * e^{b_1 t}$.

The general form of this function will be referred to as the exponential growth function throughout the remainder of this study.

The function in logarithmic form is estimated by using ordinary least squares using historical per acre yield data.

(18) $\ln Y_t = \ln B_o + b_1 * t$.

The estimated b_1 is used directly in the model as technological or productivity change. However, it is really only an estimate of the historical change in yields or production, and not productivity. Riggs (1981) explains the difference between production and productivity:

> "Productivity is more than a measure of production. An increase in production means the value of output has risen, but does not necessarily mean productivity has increased. Quantity produced is just the numerator in the productivity ratio. The denominator contains the inputs required for the given output. If added output is attained at the expense of a disproportionate increase in input, productivity declines even as production climbs. Awareness of such relationships becomes more important as the need to conserve resources becomes more critical."

Taylor's method of estimating yield change is correct, as long as it is recognized as nothing more than an estimate of yield change, and used only to project future yields. Taylor uses it as an estimate of technological change in his projections of future income, i.e., estimates of future yields, multiplied by price, provide estimates to obtain gross income. Net farm income then is calculated as gross income minus fixed costs and variable costs. Here a critical error is made. Throughout the length of analysis, these fixed and variable costs remain constant. Every dollar increase in gross income translates into a dollar increase in net income. The model thus forces both increase in production and productivity. It underestimates production and depreciation costs and overestimates net farm income.

Historically, the production inputs used in crop production have changed. For example, agricultural fertilizers and pesticides made up three percent of total farm inputs in 1950, and 16 percent in 1975. During the same period, the amount of farm labor has decreased considerably yet overall the inputs per acre, measured in real dollars, have increased (Lu, Cline, and Quance, 1979). This raises the question of whether costs have increased with yields.

To test the relation, as used by Taylor, that variable costs and depreciation costs have remained constant, the following procedure was executed. Idaho crop production expense and depreciation data were used to estimate the historical rate of change of per acre variable cost and depreciation. These data were converted to real dollars by deflating them by the index of prices paid by farmers for production items, interest, taxes, and wages for each respective year. They were then put on a per acre basis by dividing the deflated value by the number of acres farmed in Idaho. The production expense, depreciation, and acreage data and the price indices were taken from the USDA's, Economic Indicators of the Farm Sector, State Income and Balance Sheet Statistics for 1949 through 1981. The following algorithm summarizes this process:

(19) $RCA_t = (NC_t/IPR_t)/TA_t$.

Where:

RCA_t = real costs per acre in year t;

NC_t = nominal costs in year t;

IPR_t = the index of prices paid by farmers for production items, interest, and wages in year t, 1910-14 = base;

TA_t = total acres farmed in Idaho in year t.

The historical rate of change of deflated per acre production and depreciation costs were then estimated by using a logarithmic transformation of the exponential growth function and ordinary least square on these data.

Similarly, Idaho cash receipt data from crop marketings were added to the net change in farm crop inventories for an estimate of the value of annual farm crop production. This amount was then deflated by the index of prices received by farmers, and then divided by the number of acres farmed to obtain per acre figures. These data were taken from the USDA's Economic Indicators of the Farm Sectors, State Income and Balance Sheet Statistics, for 1949 through 1981. Using a logarithmic transformation of the exponential growth function, and ordinary least squares, estimates were then obtained.

A productivity ratio then was constructed which had the following form:

(20) Productivity Ratio = Output per acre/costs per acre.

The site specific ratios constructed were the following:

$$\text{(21) Variable Cost Productivity Ratio} = \frac{\text{deflated output per acre}}{\text{deflated variable costs per acre}}$$

$$\text{(22) Depreciation Cost Productivity Ratio} = \frac{\text{deflated output per acre}}{\text{deflated depreciation per acre}}$$

The growth rates of these ratios were then estimated using ordinary least squares and a logarithmic transformation of the exponential growth function. If the productivity ratio grows at a positive rate over time, it suggests that output is increasing faster than the variable costs or depreciation, i.e., output and variable costs and depreciation do not grow at the same rate. These estimated productivity growth rates were then used to generate site specific growth rates for both variable and depreciation costs. This was accomplished with the following algorithm:

$$(23)\quad [(\frac{1 + \text{growth rate of crop yield}}{1 + \text{growth rate of productivity ratio}}) - 1]$$

This algorithm uses two pieces of known information, the growth rate of per acre crop yields estimated with equation 18, and the growth rate of the respective productivity ration estimated with either equation 21 or 22. An implication of this algorithm (23) is that productivity of the study site will increase at the state's historical rate.

The variable cost growth rate for each crop is calculated with the following algorithm:

$$(24)\quad VCGR = [(\frac{1 + YGR}{1 + VPG}) - 1]$$

Where:

VCGR = variable cost growth rate;

YGR = yield growth rate;

VPG = variable cost productivity ratio growth rate.

The depreciation cost growth rate is calculated with the following algorithm:

$$(25)\quad DCGR = [(\frac{1 + WYR}{1 + DPG}) - 1]$$

Where:

DCGR = depreciation cost growth rate;

WYR = the weighted average yield growth rate of the crops grown on the study area. (The weights are the percentage of the study area in each crop.)

DPG = depreciation cost productivity ratio growth rate.

The initial per acre variable cost of production for each crop is a representative crop production budget. Variable costs are now calculated by the following algorithm:

(26) $VC_t = (IVC)e^{VCGR_t}$.

Where:

VC_t = variable cost per acre at time t;

IVC = initial per acre variable cost of production;

t = time period;

e = exponential operator;

VCGR = variable cost growth rate.

Changes in Initial Capital Investment

Depreciation cost used by Taylor was based on the current purchase price of equipment and zero salvage value at the end of 10 years. This method of calculating the initial depreciation level could overestimate the true initial depreciation cost for two reasons. First, the equipment complement assumed by Taylor and used on the farm size assumed by Taylor, would still have a significant salvage value after 10 years (Mohasci et al., 1980). Therefore, salvage value should be subtracted from initial purchase price of equipment to more accurately reflect actual amounts of capital being consumed through time. Secondly, depreciation based on current purchase prices of new equipment could be overestimated for the following reason. Yields are a function of the technological level of capital used to produce yields as well as the amount of capital used. The yield-topsoil depth function is estimated by area yield data. These yields are produced with equipment of various ages and various technological levels. Therefore, calculating depreciation based on the highest level of technology is not consistent. This inconsistency has the effect of overestimating depreciation and underestimating net farm income in the early years of the simulation. Initial depreciation, therefore, is calculated with the following algorithms:

(27) $CI = PP - SV$.

Where:

CI = capital investment;

PP = purchase price of a new equipment complement;

SV = salvage value of the equipment complement based on the hours of use after 10 years.

(28) $ICI = (CI)e^{DCGR(-4.5)}$.

Where:

ICI = initial capital investment, i.e., at time 0;

CI = capital investment from equation 27

e = the exponential operator;

DCGR = the depreciation cost growth rate;

-4.5 = assumes 10 percent of all equipment had been replaced each year by new equipment.

The opportunity cost of the average capital investment is now calculated by the following algorithm:

(29) $OCC_t = (ICI)e^{DCGR_t/2} * MIR.$

Where:

OCC_t = opportunity capital cost in time period 't';

MIR = interest rate available on alternative investment;

ICI = initial capital investment.

Depreciation for the entire farm is now calculated with the following algorithm:

(30) $DC_t = (ICI)e^{DCGR_t} * 0.10.$

Where:

DC_t = total farm depreciation cost at time t;

ICI = the initial capital investment;

DCGR = the depreciation cost growth rate;

t = the time period;

e = the exponential operator.

The Price

The Taylor model assumes a constant real output price throughout the length of a simulation. The output prices used are simple, five-year weighted average prices. The Taylor model also assumes constant real input prices throughout the simulation. The relative level of output and input prices is an important factor affecting the profitability of a farm. If the output/input price ratio declines, real farm income will be less than it would have been had no decline in this price ratio occurred. It was hypothesized that real output prices have changed through time. This was tested by the following procedures.

The index of prices received by farmers for food grains, the index of prices received by farmers for feed grain, and the index of prices paid by farmers for production items, interest, taxes, and wages from the USDA's Economic Indicators of the Farm Sector, State Income and Balance Sheet Statistics, for 1938 through 1981 were used to construct parity ratios. These parity ratios were constructed by deflating the index of prices received by farmers for each of the indexes (food and feed grains) by the index of prices paid by farmers. Then the rates of change of these ratios were estimated using a logarithmic transformation of the exponential growth function and ordinary least squares. The following algorithm was added to the model to permit the modeling of changes in real output prices:

(31) $P_t = (P_o)e^{at}$.

Where:

P_t = the crop price at time t;

P_o = the crop price at the beginning of the simulation;

a = the growth rate of relative prices;

t = the time period;

e = the exponential operator.

The initial crop price also was changed. Instead of using a weighted average of past prices, the more important factor of relative prices between inputs and outputs was incorporated by using a price reflecting the average parity ratio over the last three years. The following algorithm reflects this price.

$$(32)\ \text{Price}_t = \left(\sum_{i=1}^{t-3} PR_i/3\right) * \left(\frac{\text{average crop price}_{t-1}}{PR_{t-1}}\right)$$

Where:

PR_i = parity ratio in year i.

Results of Refining the Taylor Model

This section presents the results of estimating the growth rates of variable costs and depreciation costs, discusses whether variable costs and depreciation costs increase at the same rate as output, and presents estimates of the productivity growth rates, historical price trend of food and feed grains, and yield growth rates. This section concludes with an explicit definition of the variable cost and depreciation functions used in this paper. The methods and data sources used for these analyses were those which were identified and discussed earlier in this chapter.

Estimation of Cost Growth Rates

The growth rates of deflated per acre variable and depreciation costs were estimated using the logarithmic transformation of the exponential function and ordinary least squares achieving the following results.

Variable Costs

$$\ln VC_t = -2.36002 + .0201759t$$

t-stats. (-117.8) (15.75)

$R^2 = .8889$

Durbin-Watson Statistic = .3177

The low Durbin-Watson statistic indicated the presence of autocorrelation. The Cochrane-Orcutt procedure will be used throughout the remainder of this paper when correcting for autocorrelation. The corrected results follow:

$$\ln VC_t = -3.42326 + .0287199t$$

t-stats. (-41.09) (7.99)

The estimated growth rate of deflated Idaho per acre variable costs, from 1949 through 1981 was 2.87199 percent per year. As indicated by the high t-statistic, this growth rate is significantly different from zero. The assumption made by Taylor, that real per acre variable costs remain constant, is not consistent with the historical trend.

Depreciation Costs

$$\ln DCA_t = -4.68479 + .0233045t$$

t-stats. (-279.0) (27.0437)

$R^2 = .959337$

Durbin-Watson Statistic = 1.1037

Autocorrelation was indicated. The corrected results follow:

$$\ln DCA_t = -4.65987 + .0221497t$$

t-stats. (-185.49) (17.922)

The estimated historical growth rate of deflated, per acre depreciation costs in Idaho was 2.21497 percent per year. The assumption implicit in Taylor's model, that real depreciation costs remain constant, does not reflect the historical trend.

Idaho Farm Output

The growth rate of deflated, per acre, Idaho crop output was estimated. The following results were obtained:

$$\ln \text{Output}_t = -2.36002 + .0280422t$$

t-stats. (-117.0) (27.08)

$R^2 = .959447$

Durbin-Watson Statistic = 1.6375

The estimated historical growth rate of deflated, Idaho crop output per acre was 2.80422 percent per year.

To indicate variability through time, the growth rates of deflated, per acre output, variable costs, and depreciation costs were estimated by decade and the corrected results are summarized in Table 1.

Table 1. Variable Costs, Depreciation, and Output Growth Rates

Years	Variable Cost Growth Rate	Depreciation Growth Rate	Output Growth Rate
1949-1981	2.87199%	2.21497%	2.80422%
1949-1961	2.52017%	.03614%	2.37950%
1962-1971	1.93049%	3.04827%	3.65119%
1972-1981	3.49749%	2.44570%	3.25580%

Estimation of the Productivity Ratio Growth Rates

The estimates of the growth rates for the productivity ratios follow:

Output to Variable Cost

$\ln PR_t = .917628 + .0055545t$

t-stats. (29.33) (3.48)

$R^2 = .281312$

Durbin-Watson Statistic = .9952

Autocorrelation was indicated. The corrected results follow:

$\ln PR_t = .940031 + .00468133t$

t-stats. (16.19) (1.66)

The estimated historical change of the output to variable cost ratio was .468133 percent per year. Therefore, output was increasing relative to variable costs at a rate of about a half percent per year. This estimate will be used later in estimating the variable cost growth rate.

Output to Depreciation Cost

$\ln PR_t = 2.32477 + .00473766t$

t-stats. (85.50) (3.39)

$R^2 = .271011$

Durbin-Watson Statistic = 1.3688

Autocorrelation was indicated. THe corrected results follow:

$\ln PR_t = 2.29266 + .00625739t$

t-stats. (68.09) (3.72)

The estimated annual growth rate of the output to depreciation ratio was .625739 percent. Therefore, output was increasing relative to depreciation at a rate of more than a half percent per year. This estimate will be used in estimating the depreciation cost growth rate. To test their variability through time, the productivity ratio growth rates were then estimated by decade and the corrected results are summarized in Table 2.

Table 2. The Historical Growth Rates of Productivity Ratios

Years	Output / Variable Cost	Output / Depreciation	Output / Variable Cost & Depreciation
1949 - 1981	.468133%	.625739%	.522707%
1949-1961	.874382%	.623091%	1.003570%
1962-1971	2.494600%	.602895%	2.058450%
1972-1981	-.241652%	.810112%	-.041509%

Estimation of Price Trends

The parity ratios of food grains and feed grains were constructed and then their growth rates were estimated with the following results.

Food Grains

$$\ln P_t = .682148 - .00903836t$$

t-stats. (9.63) (-3.30)

$R^2 = .205587$

Durbin-Watson Statistic = .3700

Autocorrelation was indicated. The corrected results follow:

$$\ln P_t = .92562 - .0172327t$$

t-stats. (4.10) (-2.23)

The ratio of the index of prices received for food grains to the index of the prices paid, decreased at an estimated annual rate of 1.72327 percent.

Feed Grains

$$\ln P_t = .776571 - .0177227t$$

t-stats. (13.14) (-7.75)

$R^2 = .588389$

Durbin-Watson Statistic = .4541

Autocorrelation was indicated. The corrected estimates follow:

$$\ln P_t = .941293 - .0229195t$$

t-stats. (6.47) (-4.47)

The ratio of the index of prices received for feed grains to the index of prices paid, decreased at an estimated annual rate of 2.29195 percent. To test their variability through time, the price ratio growth rates were estimated by decade and the corrected results are summarized in Table 3.

Table 3. The Historical Price Ratio Growth Rates

Years	Index of Prices Received for Food Grains / Index of Prices Paid	Index of Prices Received for Feed Grains / Index of Prices Paid
1938-1981	-1.72327%	-2.29295%
1938-1951	4.06550%	.12151%
1952-1961	-3.34529%	-6.16332%
1962-1971	-6.26381%	-2.84621%
1972-1981	-9.86216%	-2.22058%

Estimation of the Yield Growth Rates

Winter wheat, spring barley, and Austrian winter peas are the only crops considered in this study because they are the principal crops of the Camas Prairie region, comprising over 85 percent of all the crops grown in Lewis County (ASCA, 1983). Historical per acre wheat and barley yield data from 1938 through 1981 were obtained from the Lewis County ASCS. The historical yield per acre growth rates of both of these crops were estimated using ordinary least square and a logarithmic transformation of the exponential growth function obtaining the following results:

Winter Wheat

$$\ln Y_t = 3.42518 + .0156928t$$

t-stats. (73.48) (8.70)

$R^2 = .642988$

Durbin-Watson Statistic = .9457

Autocorrelation was indicated. The corrected estimate follows:

$$\ln Y_t = 3.41469 + .0159361t$$

t-stats. (37.28) (4.72)

The estimated annual growth rate of per acre winter wheat yields was 1.59361 percent.

Spring Barley

$$\ln Y_t = 3.30296 + .00118172t$$

t-stats. (57.01) (5.27)

$R^2 = .383721$

Durbin-Watson Statistic = 1.6751

The estimated annual growth rate of per acre barley yields was 1.18172 percent. These estimates will be used throughout the remainder of this study. An estimate of the growth rate of per acre Austrian winter pea yields could not be made directly because pea yield data for Lewis County were not available. Therefore, the growth rate of pea yields estimated by Taylor (1982) for Whitman County, Washington, an area of similar rainfall, will be used as a proxy. This estimated annual growth rate was .975547 percent.

Explicit Description of the Cost Function

The functions for the variable cost of production of winter wheat, spring barley, and Austrian winter peas follow:

Winter Wheat

$$(34)\quad VC_t = (IVC)e\left[\left(\frac{1.015936}{1.0046813}\right) - 1\right]$$

$$= (IVC)e^{.01120236t}$$

Spring Barley

$$(35)\quad VC_t = (IVC)e\left[\left(\frac{1.0118172}{1.0046813}\right) - 1\right]$$

$$= (IVC)e^{.00710265t}$$

Austrian Winter Peas

$$(36)\quad VC_t = (IVC)e\left[\left(\frac{1.0097554}{1.0046813}\right) - 1\right]$$

$$= (IVC)e^{.00505050t}$$

Where:

VC_t = variable cost per acre in time t;

IVC = the variable cost of production of the crop at the beginning of the simulation.

All other terms have been previously defined.

These per acre variable cost functions imply that increases in per acre variable costs are independent of actual crop yields. They imply that the variable costs of an eroded area with low yields are the same as the variable costs of a high yielding area. This assumption is reasonable. Most of these variable costs vary with acres planted and not with actual yields. Once the decision to plant is made, many of these costs such as tillage and planting costs, become fixed. Others, such as harvest costs, vary little with yields. Fertilizer costs may decline with topsoil depth and yield. However, some of this cost decline would be offset by higher equipment repair and field costs incurred when tilling shallow, eroded, and low yielding soil.

The depreciation cost function uses a weighted average yield growth rate, to reflect the fact that all crops use a common equipment complement. The weighted average yield growth rate is calculated as follows:

(37) Weighted Average Yield Growth Rate = $YGR_i W_i$.

Where:

W_i = the percentage of the total study area planted to the crop (winter wheat = .5; spring barley = .33; A.W. peas = .167).

The weighted average yield growth rate is calculated to be .01349689.

The total farm depreciation cost function follows:

$$(38)\quad DC_t = (ICI)e\ [(\frac{1.01349689}{1.00625739}) - 1]$$

$$= (ICI)e^{.0071945t}$$

Where:

DC_t = total farm depreciation cost in time t;

ICI = the initial capital investment.

All other terms have been previously defined.

RESULTS

The study area of this analysis is a representative farm on the Camas Prairie. It is comprised of 1,122 acres, the average size of all farms in Lewis County which have sales more than $2500. The individual study sites are land classes categorized by their slope. The representative farm is divided into six slope classes, their acres being proportional to the slope classes of the Long-Hollow Creek Watershed.

The crop rotation used in the representative farm simulation is an annual cropping rotation which includes winter wheat, spring barley, and Austrian winter peas. One-half of the farm is in winter wheat, one-third in spring barley, and one-sixth in winter peas.

Although some summer fallowing is still practiced on the Camas Prairie, an annual cropping rotation is becoming the standard practice.

Three tillage systems are evaluated in this study -- heavy tillage, reduced tillage, and no-till. The tillage practices used are representative of those practices used on the Camas Prairie. The Universal Soil Loss Equation is used to estimate the soil loss for the alternative systems.

The current prices of the machinery complement are used to calculate the initial capital investment. Heavy tillage has the highest capital investment ($233,017), followed by no-till ($200,895), and reduced tillage ($199,508). No-till had a slightly higher capital investment than reduced tillage because the no-till drill is almost twice as expensive as the conventional drill. This increase in drill costs more than offset the decrease in other tillage equipment when moving from reduced tillage to no-till.

Variable costs of production included equipment operating costs, seed, fertilizer, and pesticides. Per acre variable costs for the three crops -- winter wheat, spring barley, and Austrian winter peas -- were highest for the no-till systems; $135.82, $91.97, and $69.99, respectively. Reduced tillage had the lowest variable costs -- $115.67, $75.70, $54.88 -- while heavy tillage costs were in between the two extremes; $121.88, $81.75, $61.26, respectively.

For purposes of comparison, five planning horizons are reviewed -- 1, 25, 50, 75, and 100 years. The real discount rate varies from 0 to 20 percent.

Simulation Comparison

The original Taylor model and the revised model were run for heavy tillage. The original Taylor model does not have a mechanism for modeling relative price changes. Therefore, the revised model simulation did not include any change in relative prices to facilitate a meaningful comparison of the two models. In revising the Taylor soil-productivity loss model, the physical components were not changed. Therefore, the erosion rate and yield outputs are identical and will not be discussed in this section. The net farm income projections, however, are different and the whole farm results are summarized in Table 4.

The sum of the undiscounted net farm income projections of the revised model are higher than those of the original model in the early years of the simulation. This occurs because the initial depreciation cost calculation of the revised model includes salvage value and is based on equipment of different levels and costs which results in a lower depreciation cost than the original model. Also, the crop prices calculated for the revised model are higher than the prices calculated for the original model.

Depreciation and variable costs grow with output in the revised model. In the original model, depreciation and variable costs remained constant as output grew, which resulted in large net income projections in the late years of the simulation.

The sum of undiscounted net income projections of the original model surpassed the projections of the revised model after 100 years because of the extremely fast income growth of the original Taylor model. However, when income is discounted, the net farm income projections of the revised model are higher than those of the original Taylor model in every year. The higher income projections of the original model occur in the later years where discounting lessens their importance.

The income projections of the revised model may seem high, but no land tax, rent, operator labor, overhead, or management charges were

Table 4. Sum of Discounted Net Farm Income Under Heavy Tillage Using the Original Taylor Model and the Revised Taylor Model in Dollars

Discount Rate	Model	Years in Simulation 1	25	50	75	100
0%	Original	40,488	1,814,671	5,865,720	12,569,166	22,393,049
	Revised	87,839	2,749,071	6,904,287	12,817,571	20,592,966
5%	Original	38,560	948,161	1,574,475	1,889,655	2,027,567
	Revised	83,657	1,482,655	2,148,125	2,429,694	2,539,905
10%	Original	36,807	555,906	675,363	694,442	697,077
	Revised	79,853	919,257	1,048,839	1,066,075	1,068,198
20%	Original	33,740	264,290	271,153	271,280	271,282
	Revised	73,199	475,903	483,573	483,689	483,691

included in the calculation of farm income. Rent on the Camas Prairie ranges between $45 and $65 per acre (Golden, 1983; Gephardt, 1983; Halfmoon, 1983). If a rent charge of $60 per acre is assumed, a farmer would have $18.29 per acre available for storage, overhead, labor, and management charges. The $60 per acre rent charge could not be met with the income projected by the original model. After rent income projected by the original Taylor model was -23.91 per acre.

Estimation and Comparison of Farm Income Under the Three Tillage Systems

Heavy tillage, reduced tillage, and no-till were simulated. Henceforth, these will be referred to as the standard simulations. The crop and input prices were held constant for these simulations. The long-term average farm topsoil depth and crop yield projections are summarized in Table 5. As expected, future topsoil depths are deepest for no-till, followed by reduced tillage, with heavy tillage resulting in the most shallow future topsoil depth. After 100 years of heavy tillage, average farm topsoil depth will have declined from 15.70 inches to 5.07 inches, a loss of 10.63 inches. After 100 years of reduced tillage, average farm topsoil depth will have declined from 15.70 to 9.98, a loss of 5.72 inches or about one-half the topsoil loss of heavy tillage. After 100 years of no-till, average farm topsoil depth will have declined from 15.70 inches to 13.63 inches, a loss of only 2.07 inches, or less than one-fifth the topsoil loss of heavy tillage.

Table 5. Average Farm Crop Yields and Topsoil Depths for Simulations of Heavy, Reduced, and No-Till Systems

Factor	Tillage System	Year 1984	2009	2034	2059	2084
Topsoil Depth (inches)	Heavy	15.70	13.06	10.31	7.56	5.07
	Reduced	15.70	14.32	12.87	11.43	9.98
	No-Till	15.70	15.20	14.68	14.16	13.63
Winter Wheat (bushels)	Heavy	59.77	84.40	118.76	162.32	216.03
	Reduced	57.08	82.18	119.66	173.34	249.49
	No-Till	56.78	82.73	122.38	180.94	267.39
Austrian Winter Peas (pounds)	Heavy	1498.71	1886.30	2372.09	2864.10	3137.45
	Reduced	1293.39	1632.03	2076.40	2634.23	3322.83
	No-Till	1264.91	1597.87	2037.97	2598.87	3313.50
Barley (bushels)	Heavy	51.92	66.43	84.36	104.08	125.06
	Reduced	49.59	64.68	84.97	111.06	144.24
	No-Till	49.33	65.10	86.89	115.90	154.22

At the beginning of the standard simulation, average farm winter wheat yields under heavy tillage are highest, followed by winter wheat yields under reduced tillage, and then under no-till. After 25 years, no-till wheat yields surpass those of reduced tillage. After 50 years, no-till and reduced tillage winter wheat yields surpass those of heavy tillage. These shifts in relative yields are the result of decreasing soil productivity from declining topsoil depths. The most erosive tillage system, heavy tillage, has the fastest rate of yield decline followed by the second most erosive tillage system, reduced tillage. Although no-till, the least erosive tillage system, begins the simulation with the lowest winter wheat yields because of the assumed yield penalty associated with it, it surpassed the yields of the other two systems in 50 years.

At the beginning of the simulation, average farm Austrian winter pea yields under heavy tillage are highest, followed by yields under reduced tillage and then under no-till. It takes 100 years before Austrian winter pea yields using no-till surpass the yields obtained using the other two tillage systems, whereas it took only 25 years for no-till winter wheat yields to surpass reduced tillage wheat yields and 50 years for no-till winter wheat yields to surpass heavy tillage yields. This was expected. The rooting depth of Austrian winter peas is more shallow than the rooting depth of winter wheat. Therefore, soil erosion should begin to adversely affect the yields of winter wheat faster than the yields of winter peas.

At the beginning of the simulation, average farm spring barley yields are the highest using heavy tillage, followed by lower reduced tillage yields, with no-till yields being the lowest. After 25 years, no-till spring barley yields surpass those of reduced tillage. After 50 years, both no-till and reduced tillage barley yields surpass those of heavy tillage.

The sum of undiscounted (0% discount rate, Table 6) net farm income under reduced tillage surpasses the sum of undiscounted net farm income of heavy tillage for a planning horizon of 50 years. Using linear interpolation, reduced tillage undiscounted net farm income was estimated to surpass heavy tillage undiscounted net farm income after approximately 30 years. The sum of undiscounted farm income of reduced tillage is superior to no-till for any of the simulated planning horizons. The sum of undiscounted net farm income for no-till surpasses heavy tillage income for a planning horizon of 100 years. Using linear interpolation, no-till undiscounted net farm

Table 6. Sum of Discounted Net Farm Income for Selected Years Under Various Discount Rates in Dollars for Various Simulation Lengths for Three Tillage Systems

Discount Rate	Tillage	Years in Simulation 1	25	50	75	100
0%	Heavy	87,839	2,749,072	6,904,286	12,817,571	20,592,966
	Reduced	85,523	2,719,436	7,015,669	13,615,131	23,524,767
	No-Till	62,063	2,096,152	5,722,406	11,704,277	21,276,679
5%	Heavy	83,656	1,482,655	2,148,125	2,429,695	2,539,905
	Reduced	81,450	1,461,824	2,146,044	2,457,198	2,595,466
	No-Till	59,107	1,114,511	1,687,440	1,967,600	2,100,325
7%	Heavy	82,092	1,206,272	1,544,778	1,634,362	1,656,306
	Reduced	79,928	1,187,889	1,535,223	1,633,867	1,661,238
	No-Till	58,002	901,929	1,919,903	1,280,500	1,306,714
10%	Heavy	79,854	919,257	1,048,838	1,066,674	1,068,198
	Reduced	77,748	903,769	1,036,367	1,055,255	1,057,884
	No-Till	56,421	682,309	792,557	809,464	811,973
20%	Heavy	73,199	475,902	483,572	483,689	483,691
	Reduced	71,269	466,109	473,907	474,034	474,036
	No-Till	51,719	347,030	353,451	353,563	353,565

income was estimated to surpass heavy tillage undiscounted net farm income after approximately 91 years.

Reduced tillage farm income discounted at 5 percent surpasses heavy tillage income for a 75 year planning horizon (Table 6). Using linear interpolation, reduced tillage discounted net farm income was estimated to surpass heavy tillage discounted net farm income after approximately 52 years. No-till has the lowest discounted net farm income at any discount rate for any length of planning horizon. The discounted net farm income for reduced tillage is higher than heavy tillage income at a 7 percent discount rate and with planning horizons of 100 years. Heavy tillage has a higher discounted net farm income than the other two tillage systems for any discount rate higher than 7 percent for any planning horizon. The projections of the sum of net farm income for the standard simulations are summarized in Table 6. The most profitable tillage system for a farmer depends on the farmer's personnel discount rate and length of planning horizon. If an individual has a long planning horizon and a low personal discount rate, according to this analysis and the assumptions implicit in it, reduced tillage could be the most profitable tillage system. If an individual has a short planning horizon and a high personal discount rate, heavy tillage is the most profitable tillage system. If an individual has a short planning horizon and a high personal discount rate, heavy tillage is the most profitable tillage system. Only in the case of the individual with a personal discount rate near zero and a planning horizon longer than 100 years, would no-till be the most profitable tillage system.

Slope Class Level Analysis

The above analyses were based on average yields from the six slope classes and on total farm income. When specific slope classes are examined, some interesting differences are highlighted. Slope classes one and six were selected for comparison with the whole farm analysis to illustrate these differences. Slope class one represents a study site with relatively deep topsoil and a low erosion rate, while slope class six represents a study site with relatively shallow topsoil and a high erosion rate. Although areas with shallow topsoil do not necessarily have high erosion rates, they often do. Shallow topsoils are often a result of high erosion rates.

The simulation results of slope class one projects a saving of only four inches of topsoil over a 100-year period if no-till is adopted over heavy tillage (Table 7). Approximately 10 inches of topsoil are saved over a 100-year period if no-till is adopted over heavy tillage on slope Class Six. After 75 years of heavy tillage, no topsoil will remain on slope class six.

Table 7. Winter Wheat Yields and Topsoil Depths for Slope Class One, Slope Class Six, and the Farm for Simulations of Heavy, Reduced, and No-Till Systems

			Year				
Factor	Tillage System	Study Site	1984	2009	2034	2059	2084
Topsoil Depth (inches)	Heavy	Slope Class 1	17.00	15.76	14.47	13.19	11.90
	Reduced		17.00	16.35	15.67	15.00	14.32
	No-Till		17.00	16.76	16.52	16.28	16.03
	Heavy	Slope Class 6	13.00	9.11	5.05	.99	.00
	Reduced		13.00	10.96	8.83	6.69	4.56
	No-Till		13.00	12.26	11.49	10.72	9.95
	Heavy	Farm	15.70	13.06	10.31	7.56	5.07
	Reduced		15.70	14.32	12.87	11.43	9.98
	No-Till		15.70	15.20	14.68	14.16	13.63
Winter Wheat (bushels)	Heavy	Slope Class 1	60.63	87.73	128.63	188.10	274.24
	Reduced		57.90	84.32	124.66	184.19	271.95
	No-Till		57.60	84.24	125.15	185.93	276.20
	Heavy	Slope Class 6	57.68	78.16	101.33	116.49	157.29
	Reduced		55.08	77.85	110.37	153.96	209.90
	No-Till		54.79	79.35	116.56	170.97	250.40
	Heavy	Farm	59.77	84.40	118.76	162.32	216.03
	Reduced		57.08	82.18	119.66	173.34	249.49
	No-Till		56.78	82.73	122.38	180.94	267.39

Yields will also decline by quite different amounts depending on the slope class. As an example, after 100 years, no-till winter wheat yields on slope class one are only about two bushels higher than heavy tillage yields on the same slope class. After 100 years, no-till winter wheat yields on slope class six are about 93 bushels higher than heavy tillage yields on slope class six. No-till yields become higher than heavy tillage yields after 100 years on slope class one, whereas after only 25 years on slope class six. The validity of the yield projections on slope class six after 75 years is questionable. After 75 years, zero topsoil depth is reached on slope class six, and, as discussed earlier, the model may not be accurate at this topsoil depth.

The initial topsoil depth and erosion rates not only influence yields but also influence per acre net income. Whether income is discounted, on slope class one, heavy tillage remains the most profitable tillage system followed by reduced tillage and then no-till in any simulated scenario (Table 8).

On slope class six, reduced tillage undiscounted income surpasses heavy tillage income for planning horizons of 25 years or longer. No-till undiscounted income surpasses heavy tillage income after 50 years and becomes equal to reduced tillage income after 100 years. However, when income is discounted at 5 percent, after 25 years reduced tillage become the most profitable tillage system, followed by heavy tillage, and then no-till. This ranking remains the same for planning horizon length of 25 years or longer.

Table 8. Sum of Discounted per Acre Net Farm Income for Selected Years Under Various Discount Rates in Dollars for Slope Class One, Slope Class Six, and the Farm

			Years in Simulation			
Rate	Study Site	Tillage System	1	25	50	100
0%	Slope Class 1	Heavy	80	2,585	6,722	23,010
		Reduced	78	1,522	6,587	22,894
		No-Till	57	1,948	5,324	19,888
	Slope Class 6	Heavy	72	2,175	5,084	10,879
		Reduced	70	2,208	5,578	17,406
		No-Till	49	1,682	4,601	17,068
	Farm	Heavy	78	2,450	6,153	18,353
		Reduced	76	2,423	6,252	20,966
		No-Till	55	1,868	5,100	18,963
5%	Slope Class 1	Heavy	76	1,387	2,045	2,486
		Reduced	74	1,353	1,999	2,438
		No-Till	54	1,035	1,569	1,955
	Slope Class 6	Heavy	68	1,182	1,656	1,848
		Reduced	67	1,190	1,729	2,060
		No-Till	47	893	1,355	1,686
	Farm	Heavy	74	1,321	1,914	2,263
		Reduced	72	1,302	1,912	2,313
		No-Till	52	993	1,503	1,871

SUMMARY AND CONCLUSIONS

Summary

Objective 1: The Review and Refinement of the Taylor 1982 Soil-Productivity Loss Model

The implicit and explicit assumptions, parameters, and relationships of the Taylor 1982 soil-productivity loss model were identified and critiqued. The original Taylor model assumes crop yields will grow at their historical rates while variable and depreciation costs remain constant. Historically, this has not happened. Idaho farm variable costs were estimated to have increased at an annual historical rate of about 2.9 percent. Idaho farm depreciation costs were estimated to have increased historically at an annual rate of about 2.2 percent. The original Taylor model was revised to accommodate increases in these costs. The initial capital investment calculation of the original model was modified to include salvage value and to reflect the fact that the yields used in the simulations were produced with equipment of different technology levels and costs.

The method of calculating initial crop prices was changed. The new algorithm reflects the relative levels of output/input prices rather than only the absolute level of crop prices. Also, an algorithm to reflect changes in the relative level of output/input prices was added to the model.

Objective 2: Comparison of the Income Estimates of the Revised Taylor Model with the Income Estimates of the Original Model.

The original Taylor model and the revised Taylor model were run for heavy tillage. A comparison of the income projections of the two models was made. Income (returns to land, labor, overhead, and management) was projected with the original model to be $38.08 per acre in the first year. Income from the revised model was projected to be $78.29 per acre. In the later years of the simulation, the income estimates of the original Taylor model surpass the income projection of the revised model. This results from the assumption of increasing yields and constant costs implicit in the original model, an assumption not made in the revised model.

Objective 3: Estimation and Comparison of Farm Income Under the Three Tillage Systems.

Heavy tillage, reduced tillage, and no-till were simulated with the revised model. Reduced tillage was found to be the most profitable tillage system for farmers with planning horizons of 75 years or longer and personal discount rates of under 7 percent. Heavy tillage was the most profitable tillage system for farmers with planning horizons shorter than 75 years. No-till was always the least profitable tillage system, although the highest yield projections were produced under no-till.

Yield and income results from a slope class with a deep topsoil and a low erosion rate were compared with the results from a slope class with a shallow topsoil and a high erosion rate. Conservation tillage was more profitable relative to heavy tillage on the shallow topsoil than on the deep topsoil.

Conclusion

The main objective of this paper was to review and, if necessary, refine the Taylor soil-productivity loss model. This model was originally developed and now revised with the intent that it would be used as a tool to assist farmers, soil and water conservationists, and other policymakers in decisions regarding the use of conservation tillage. To be a useful tool, it must be flexible enough to model many different scenarios. In this respect, the revised soil-productivity loss model is a better model than the original model. The revised model is capable of modeling changes in variable costs, depreciation costs, and relative prices, changes that were shown to have occurred in the past and probably will occur again.

For farmers with long planning horizons, and it was argued that 100 years may possibly be the appropriate planning horizon for landowners, reduced tillage was projected to the most profitable tillage system on a representative Camas Prairie farm. For farmers with a short planning horizon and a high personal discount rate, heavy tillage is the most profitable tillage system. No-till was projected to be the least profitable tillage system under any of the simulated scenarios. This analysis was based on a representative Camas Prairie farm. Farms having different physical and economic factors such as erosion, land quality, topsoil depth, farm size, machinery complement, and pesticide requirements probably would have different income projects than those of this analysis. Ultimately, the decision of what tillage system to use is made by the individual farmer. The farmer must provide model inputs pertinent to his situation and outlook for meaningful simulations to guide this decision.

With many farmers facing monthly debt service payments, the short-term financial survival of the farm is often the most important planning criterion with long-term profitability being secondary. A successful public policy to reduce soil erosion must recognize this cash-flow predicament of the farmer. In areas such as the Camas Prairie, where reduced tillage may already be the most profitable tillage system in the long-run, policies which would alleviate cash-flow problems and allow farmers to consider long-term profitability may aid in the adoption of conservation tillage. Adoption of conservation tillage is affected by many other important considerations. Analysis of these considerations is beyond the scope of this paper. A partial list for future reference is provided in the hope that future studies might address some of these concerns.

- Reinvestment and disinvestment associated with changing tillage systems.
- Retention of conventional equipment as a hedge against failure of the new system.
- Risk and uncertainty associated with yields of crops grown under new, to the farmer, tillage practices.
- Long-term profitability varies according to soil resource situations. Therefore, a given farmer may want to retain both conventional and conservation tillage equipment.

Yield loss resulting from the use of heavy tillage was much greater on the slope class with relatively shallow topsoil than on the slope class with relatively deep topsoil. This made conservation tillage more profitable on the shallow soil than on the deep soil. Thus, a farmer may benefit by using two different tillage systems on his farm, heavy tillage on the deep soils less prone to erosion, and conservation tillage on his shallow, more erosive soils. However, the machinery complement would then be increased resulting in higher equipment costs. The difference in relative profitability of conservation tillage between different slope classes also indicates that conservation tillage may be more profitable for farms with more erosive land than for farms with less erosive land.

A final comment is needed to put the analysis in perspective. Farmers, equipment producers, and agronomists are still on an upward sloping learning curve with respect to reduced tillage and no-till farming practices. Because of this, a tillage-yield penalty was imposed on reduced-tillage and no-till. The analysis is sensitive to the size of this tillage-yield penalty. If the penalty is eliminated, reduced tillage becomes the most profitable system. No-till continues to be the least profitable of all three tillage systems under all simulated scenarios. If yield penalties were doubled, heavy tillage would be the most profitable tillage system, even though in many soil depth/slope conditions, the soil would be completely depleted during the 100-year planning horizon. Discount rates, safe minimum standards, option demand for future generations, and a basic conservation ethic are all important considerations that must be considered when using economics to determine tillage practices.

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