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Soil conservation

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A FARM LEVEL STUDY IN THE ECONOMICS OF SOIL CONSERVATION: THE PALOUSE OF THE NORTHWEST

by

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SOIL CONSERVATION: THE PALOUSE OF THE NORTHWEST

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In many respects, it appears that the economics of soil conservation has been a neglected subject in agricultural economics during the last two or three decades. The most obvious reason for this apparent lack of interest in the subject is the view that advances in technology have made soil resources *per se* of less consequence for agricultural production. One outstanding example of the impact which technical change has had is in nitrogen fertilization since World War II.

In 1940, Ibach focused on topsoil in the cornbelt as the critical resource determining value of agricultural land and used pounds of nitrogen per acre in the topsoil as a measure for estimating land values. With cheap sources of inorganic nitrogen made available by modern technology and its widespread use, this attention to topsoil as a source of nitrogen is largely obsolete. In a sense, topsoil was transformed by modern technology from a primarily stock resource into a largely renewable resource for purposes of practical decisions.

In spite of advances in technology, those already experienced and forthcoming, economic trade-offs in soil conservation can be important. Economic knowledge in soil conservation, which is usually quite specific to localized areas and regions, could be important in national agricultural policy decisions, as well as useful information for improved resource allocation at the farm level. The modest purpose of the research reported here was to show what can be learned by an application of modern economic methodology to a region which is prone to soil erosion. A secondary objective is to show that the approximation method given in (Burt and Cummings, 1977) works extremely well in applications to soil conservation. For purposes of this session, the application illustrates the three tasks involved in applied economic studies of natural resource systems: specification, estimation, and analysis.

The Wheat-Pea Area of The Palouse

The study area is what is commonly called the wheat-pea area of The Palouse, and lies mostly in Eastern Washington and Western Idaho. The soil is rich and precipitation is usually adequate to produce relatively high yields of wheat, but the topography is rolling hills with steep slopes which create soil erosion problems when farmed. The average slope of the land is about 13 percent, but some of the steeper slopes which are farmed approach 50 percent (Pawson, et.al.). This region probably has the roughest topography of any area in the U. S. which is planted to significant acreages of wheat.

The soil is a deep loess with a soil mantle depth of over 100 feet except in the bottoms of the draws where the minimum depth is about 10 feet. Therefore, soil erosion does not threaten the most basic soil resource, namely, the soil mantle of potentially productive parent material.

The primary hazards from soil erosion are gullying and loss of organic matter and topsoil. Depth of the topsoil varies considerably in relation to the slope and location on the hill. The tops of the hills have relatively shallow topsoils of less than 6 inches with relatively low percentage organic matter. In general, the depth of topsoil increases with movement down the slopes of the hills, reaching 24 inches near the bottom, and the average depth on the lower slopes is 21 to 24 inches. Percentage organic matter in the top 6 inches tends to increase with the depth of topsoil and averaged about 3.3 percent in 1960 (Pawson, et.al.).

Specification of the Model

Since soil losses are not a threat to the soil mantle itself on the loess soil of the study area, two state variables, (1) depth of topsoil, and (2) percent organic matter in the top 6 inches of soil, would appear to capture the essential information in the dynamic optimization problem of soil conservation decisions. State variables in a dynamic optimization problem must encompass sufficient information on the decision process so that when the state variables are at given levels at a point in time, the history of the decision process is almost completely subsumed for purposes of optimal decisions in the future. To illustrate this point, suppose the soil contained a root restricting layer within about 3 feet of the surface, then our 2 state variables would not be adequate because a third state variable would be necessary to reflect the depth of soil above the restrictive layer. The state variables can hardly subsume all of the pertinent information on the history of the decision process, but must so so within the limits of approximations which are considered acceptable for an empirical model. The two state variables specified here will suffice if the soil is relatively homogeneous in its vertical profile.

Strictly speaking, there are many other state variables associated with plant nutrients and the soil chemistry, but we sweep these aside and focus on variables more directly affected by erosion. Plant nutrients and various measures of the soil chemistry are affected by soil erosion, but physical soil losses and changes in organic matter (our two state variables) should indirectly measure a substantial part of the influence of erosion on individual nutrients and changes in the soil chemistry, also some of the changes in the biological base of the soil.

For a given soil (particular location), depth of the top soil and percent organic matter taken jointly probably reflect general soil fertility quite well. This statement should not be construed to mean that these two variables would explain most of the variation in fertility across locations because the basic parent material would be changing across locations, as well as other factors associated with location. In soil conservation decisions, we are concerned with changes in productivity over time at a given site, thus we expect the two state variables to jointly reflect changes in fertility with sufficient accuracy if the fertilization, cultural practices, and crop rotations are also taken into account in the dynamic model.

Another important role of these two state variables is to indirectly measure soil structure which is fundamental to soil aeration and water permeability. In the steeply rolling hills of The Palouse, good water penetration of the soil is extremely important in crop production. Poor soil structure on steep slopes could seriously depress wheat yields because of poor utilization of rainfall.

The decision variables are all possible farming practices and crop rotations which jointly affect soil organic matter, physical soil losses through erosion, and net cash flow from the land resource. We do not consider "lumpy" investments such as the construction of terraces. Obviously, some method must be devised to reduce the number of decision variables down to a feasible number, preferably one or two.

The empirical measures and data for this application came from (Horner, et.al) and (Pawson, et.al.) which largely determined the set of cultural practices and rotations to be considered. Fertilization and cultural practices were taken as given, leaving the decisions to a choice of rotations. It turned out that a single decision variable, percent of the land in wheat, could be used by selecting rotations on the basis of maximum net returns per unit of annual soil losses. A few rotations dominated the others by this criterion, and changes in organic matter are highly correlated with soil losses. Therefore, the rotations which gave maximum net returns per unit of soil losses also tended to be favorable with respect to soil organic matter.

Although the percent of land area in wheat cannot be treated as a strictly continuous variable, the model was specified with a continuous decision variable so that an approximation procedure for dynamic optimization models could be evaluated precisely. If one is willing to interpolate between rotations already tested in experiments and small modifications in these rotations, then the measures required in the economic analysis can be estimated for many different levels of the decision variable (percent of land in wheat). There is also an opportunity to use different rotations on several areas of the total farm and thus provide additional levels of the percent of land devoted to wheat. Consequently, treatment of the decision variable as if it were a continuous variable is not a serious assumption.

Crop rotations tend to be a rather static concept where we think of a separate field for each year of the rotation. To be completely accurate, crops grown on various fields of the farm within the past few years would need to be introduced as state variables and a decision variable would be required for each field to designate which crop to plant. Nevertheless, a model containing only depth of topsoil and percentage organic matter as state variables, with average percent of the land in wheat as a decision variable, will work quite well because the state variables change very slowly over time. In fact, we could specify the discrete time period of the dynamic model as a five or ten year period without much loss in precision, but we use an annual model. The derived decision rule from the annual model must be interpreted rather loosely since we know that crop rotations will be changed infrequently; more will be said on this point when the empirical results are presented.

The appropriate criterion is maximum present value of net returns from the land resource over an infinite planning horizon. If the farmer's planning period is finite, we assume that the market for land will reflect the implicit value associated with various levels of the state variables. The following notation is introduced:

x = depth of the topsoil (inches)

y = percent organic matter in the upper 6 inches of the soil

u = percent of the land in wheat

r = the discount rate (in real terms adjusted for inflation)

$\phi(u,x,y)$ = annual soil loss function (inches)

$h(u,x,y)$ = annual organic matter loss function (same units as y)

$G(u,x,y)$ = annual net returns function (dollars per acre)

The dynamic optimization model can be stated as:

$$(1) \quad \sum_{t=1}^{\infty} G(u_t,x_t,y_t)/(1 + r)^t$$

a maximum with respect to u_1, u_2, . . . subject to

$$(2) \quad x_{t+1} = x_t - \phi(u_t,x_t,y_t)$$

$$(3) \quad y_{t+1} = y_t - h(u_t,x_t,y_t) \; .$$

Estimation of Functional Relationships

All of the empirical measures and data are taken from (Pawson, et.al.) and (Horner, et.al.). To some extent, the model had to be simplified to accomodate the limited information which is available.

The data presented in Table 18 of (Pawson, et.al. p.51) on various crop rotations is used as the primary basis for determining the functions $G(u_t,x_t,y_t)$, $\phi(u_t,x_t,y_t)$, and $h(u_t,x_t,y_t)$, i.e., annual net returns, soil losses, and organic matter losses. Annual changes in organic matter for the first 10 rotations in Table 18 are given in the last row of Table 15 in (Pawson, et.al., p.31); the changes are from a base of 3.3 percent organic matter. Comparable changes in organic matter from three of the remaining 13 rotations of Table 18 were obtained from a linear regression between organic matter changes and soil losses. The regression used only those rotations which included alfalfa hay and winter wheat because these rotations dominated the other rotations on the basis of net returns per unit of soil losses. Six rotations were ultimately selected as an empirical basis for estimating the three functions in (1), (2), and (3); these were the rotations associated with rows 3, 8, 10, 18, 20, and 23 in Table 18 of (Pawson, et.al.).

Prices assumed for the calculation of net returns are given in Table 1. The results in (Pawson, et.al.) are for about 1957-58 prices and costs; inflation by the index of prices paid by farmers gives relative prices which look quite reasonable for long-run norms in 1978. Relatively heavy nitrogen fertilization of wheat is assumed, see Table 11 in (Pawson, et. al., p.27). Yield of wheat is for typical conditions in the study area in the 1950's; average depth of topsoil is 18 inches and average organic matter is 3.3 percent.

A relationship between wheat yields and the state variables is required, and this was available in (Pawson, et.al., p.66):

Table 1

Prices of Crops Used in the Analysis

Crop	1957-58 Price	1978 Price1/
Wheat (bu.)	1.60	4.20
Dry Peas (100 lbs.)	3.50	9.10
Alfalfa Hay (ton)	15.00	39.00

1/ Based on prices paid by farmers, including interest, taxes, and wage rates.

Table 2

Net Return Equation Parameters1/

Wheat Price (1957-58 dollars)	b_o	b_1	b_2	c
$1.60	5.41	.06635	-.001023	56.16
1.20	5.48	-.02453	-.001089	42.12

1/ These parameters and prices can be converted to a measure in 1978 dollars by multiplication by 2.6.

(4) $Y = a + 35.1[(1 - .9^x)(1 - .6^y)]$

where x is depth of top soil and y is percentage organic matter in the top 6 inches of soil. The parameter "a" is a constant representing yield which is theoretically obtainable on subsoil.

Gross returns and costs per acre for each rotation were given in (Pawson, et. al.) for average topsoil depth and organic matter equal to 18 inches and 3.3 percent, respectively. Percent of the land in wheat under each rotation is also available. We used the wheat yield equation in (4) to calculate a gross value attributable to the state variables, namely,

(5) $P_w(35.1)(1 - .9^{18})(1 - .6^{3.3}) = 24.3\ P_w$,

where P_w is the price of wheat. For a given rotation and price of wheat, the constant in (5) was multiplied by the percent of land in wheat and subtracted from gross returns, and then costs subtracted to get a measure of net returns, which when added to (5) would be total net returns for that rotation expressed as a function of the state variables.

Let the net returns partitioned in this way be denoted

(6) $R(u;P_w) + P_w(35.1)(1 - .9^x)(1 - .6^y)$,

where u is the percent of land in wheat. For each of the 6 "efficient" rotations selected, as described earlier, we have a unique value of u and a calculated value of $R(u;P_w)$ at a given wheat price. A quadratic function was fitted to these 6 data points to get an estimate of $R(u;P_w)$ with price at \$1.60 and \$1.20 in 1957-58 dollars (\$4.20 and \$3.10 in 1978 dollars). These two fitted equations serve as our empirical estimate of G(u,x,y) and are of the general form

(7) $b_0 + b_1u + b_2u^2 + c(1 - .9^x)(1 - .6^y)$.

Parameter values for the two different prices of wheat are given in Table 2.

The rotation data in (Pawson, et. al) give organic matter losses from a base of 3.3 percent, but this information is not adequate to estimate h(u,x,y). A linear relationship between average annual changes in organic matter (percent) and the level of organic matter at the time of initial sampling was presented in Figure 3 of (Horner, et.al., p.10), which suggests that a linear first order difference equation would describe the dynamics of soil organic matter. Average annual changes of several years is a good estimate of year to year changes for a given level of organic matter because the changes are so small.

We postulate the following general relationship for soil organic matter changes in the top 6 inches of soil

(8) $y_{t+1} - y_t = \alpha(u) + \beta y_t \ , \ \beta < 0 \ .$

The constant term $\alpha(u)$ is dependent on the crop rotation, but within our decision model, the percent of land in wheat, u, determines the crop rotation. The parameter β was estimated to equal -0.01 from the graph in Figure 3 of (Horner, et.al.). Later checks on the data suggested that β was quite stable across many rotations and approximately equal to -0.01.

The intercept $\alpha(u)$ in (8) was estimated for each of the selected 6 rotations from the information on annual changes in organic matter from a base of 3.3 percent given in (Pawson, et.al.) under the assumption that β equals -0.01. From (8) it is seen that

(9) $\alpha(u) = y_{t+1} - (1 + \beta)y_t \ .$

The information on individual rotations lets us calculate the right hand side of (9) when $y_t = 3.3$. The 6 rotations gave 6 data points for u and $\alpha(u)$ to which a quadratic function was fitted. Using this equation for $\alpha(u)$ and (8) with $\beta = -0.01$ gave the following estimate:

(10) $h(u,x,y) = -.0452 + .857(10)^{-4}u + .478(10)^{-6}u^2 + .01y$

Notice that depth of topsoil, x, does not enter in (10) and h(u,x,y) is defined as losses in organic matter.

We could not find sufficient data or information from published work to estimate the influence of soil organic matter on soil erosion losses. Therefore, soil losses were estimated as a function of the decision variable u, independently of the state variables. Soil losses were given in (Pawson, et.al.) for each rotation which gave us 6 data points in association with our 6 selected rotations. A quadratic function was fitted to these data points to get

$$(11) \quad \phi(u,x,y) = .0025 + .000261u + .1286(10)^{-5}u^2 ,$$

which completes the empirical measurement task.

Analysis of the Model

Solution of the optimization problem in (1) to (3) results in a decision rule expressing the decision variable u as a function of the state variables x and y. An approximation to this decision rule was obtained by using the methodology presented in (Burt and Cummings 1977). An exact solution can be obtained by application of nonlinear programming to the optimization problem (Burt and Cummings 1970). Probably the most practical method to get an exact solution to a problem of this dimension is with dynamic programming (Bellman).

The approximately optimal decision rule for the soil conservation application is a special case of the equations in (26) of (Burt and Cummings 1977, p.16); only one equation out of the two given there is required because we have only one decision variable. A simple computer program was written to calculate the solution of the equation implied by the approximately optimal decision rule. Each state variable was started out at its lower bound and systematically incremented after a solution for the decision variable was obtained for a given pair of values of the state variables. This procedure generated the decision rule for the entire domain of the two state variables.

Solutions were computed for a range of interest rates too, but results reported here are for a 6 percent rate; the decision rule was quite stable for rates of 4 to 8 percent.

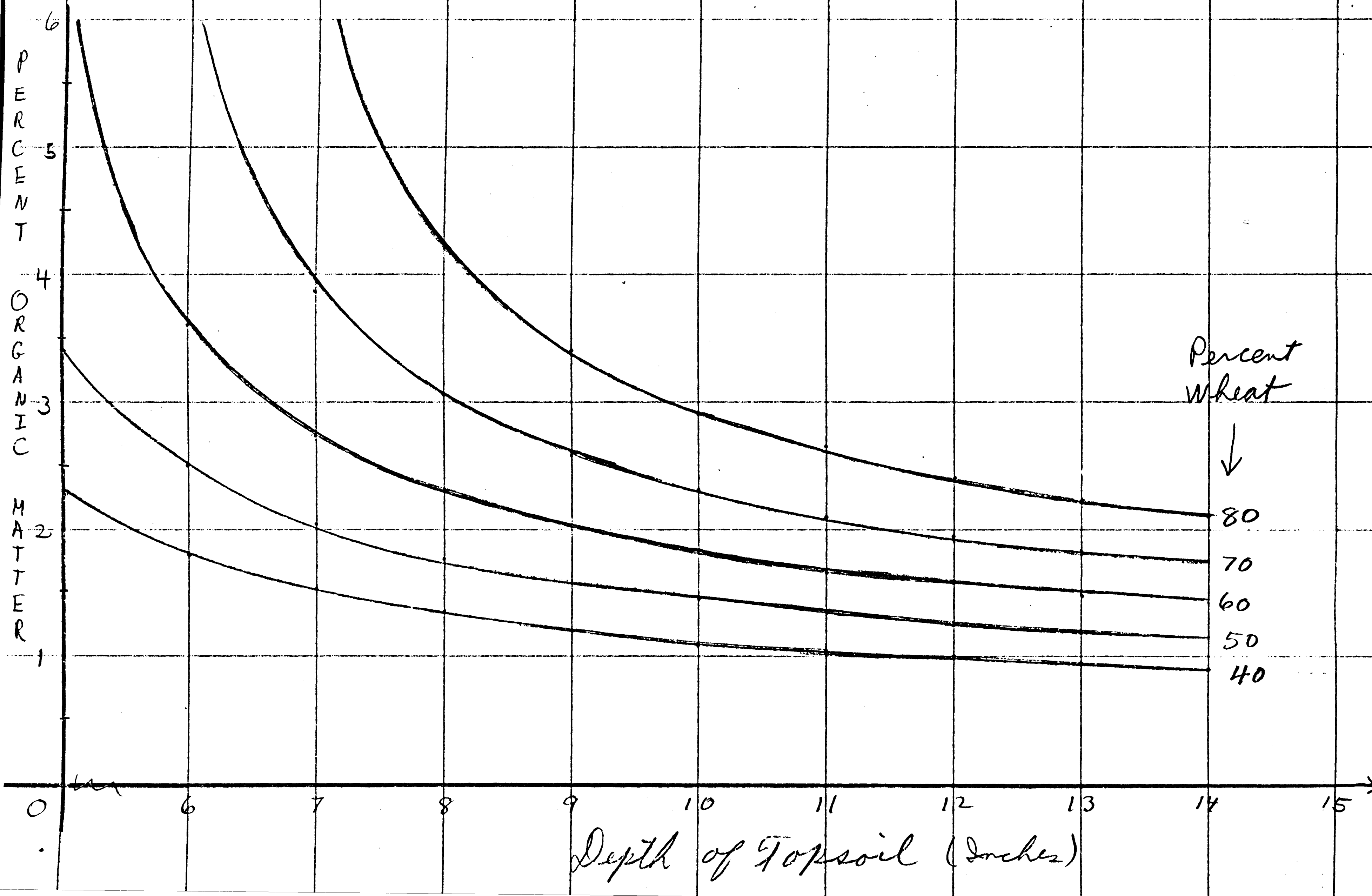
Under a wheat price of $4.20 per bushel in 1978 dollars, the decision rule is at its upper boundary of 87.5 percent wheat for nearly the entire domain of the state variables. The only exception is at extremely low levels of organic matter, less than 1.5 percent if topsoil is 6 inches or more. In other words, when the topsoil is 6 inches deep or more and soil organic matter is 1.5 percent or more, 87.5 percent of the farm's cropland should be in wheat. The upper bound of 87.5 percent wheat was imposed because at least one year in eight would be required out of wheat for purposes of disease and weed control.

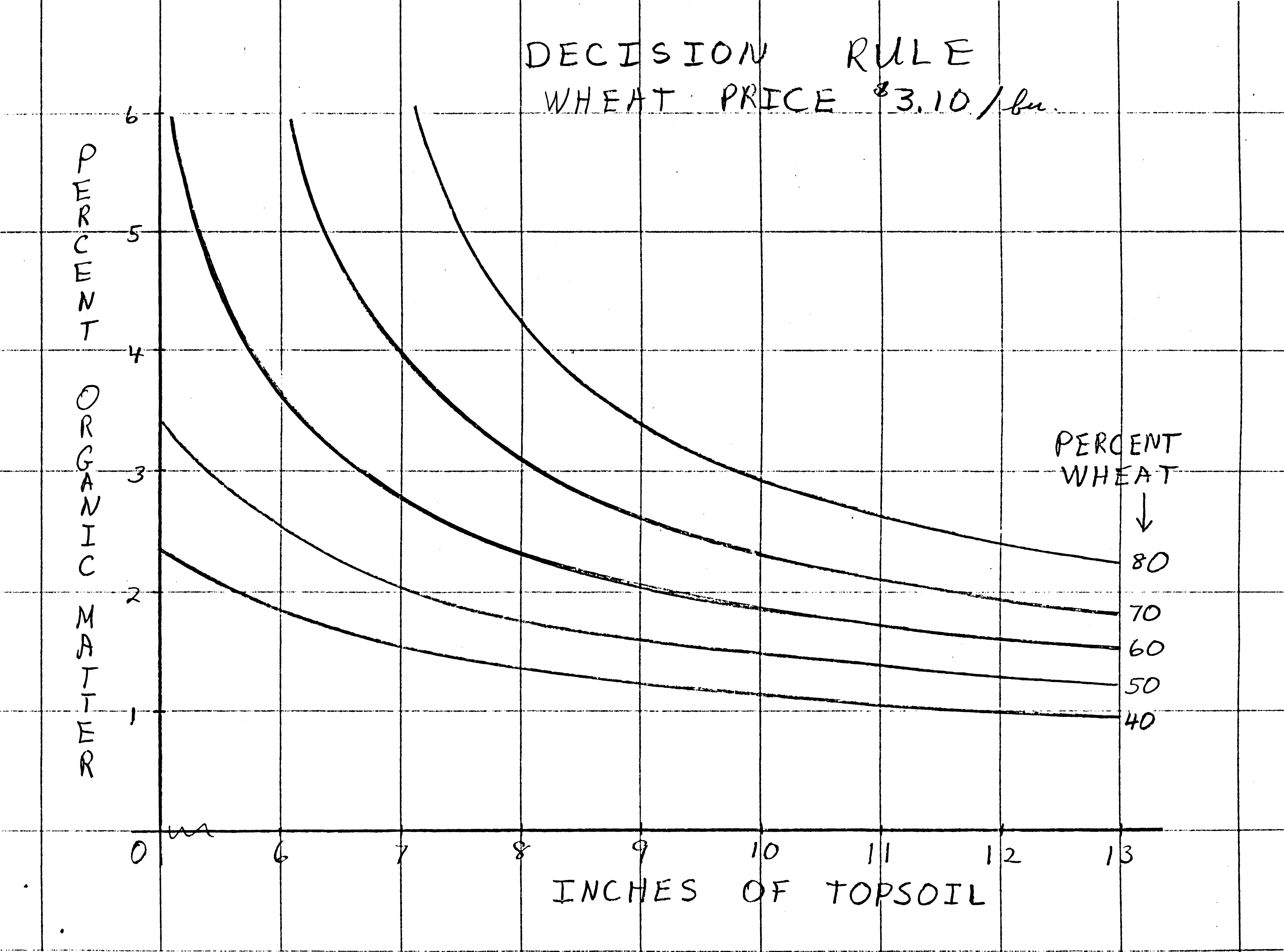
This intensive utilization of the land is not as exploitive as it might seem when the wheat is fertilized quite heavily with nitrogen as is assumed in this model. Under this land utilization, equilibrium soil organic matter is about 3.5 percent, and annual soil losses are around 4.75 tons (.035 inches) per year. At this rate of soil loss, it would take 28 or 29 years to lose an inch of topsoil. Looking at the results in this perspective leaves us with no surprises in the outcome.

When wheat price is reduced to $3.10 per bushel in 1978 dollars, the decision rule is much more interesting. This is a rather low price for wheat though. The decision rule is summerized in Figure 1 with contours on the decision rule surface. As would be expected, a small part of the farm is planted to wheat when soil organic matter is low simultaneously with a relatively shallow top soil, and vice versa.

The decision rule in Figure 1 suggests that the equilibrium level of soil organic matter, while holding depth of top soil constant, would increase

Figure I. Decision Rule for Wheat at $3.10/bu. (1978 dollars)
Percent of Land in Wheat





DECISION RULE
WHEAT PRICE $3.10/bu.
PERCENT ORGANIC MATTER
6
5
4
3
2
1
0
6
7
8
9
10
11
12
13
INCHES OF TOPSOIL
PERCENT WHEAT
80
70
60
50
40

with a decrease in the depth of topsoil. This tendency does hold; the equilibrium percentage organic matter is equal to 3.4 with 18 inches of topsoil and equal to 3.8 with only 6 inches of topsoil. At these equilibrium levels of organic matter, it would take 28 years to lose an inch of top soil when its depth is now 18 inches, and it would take 38 years to lose an inch if topsoil depth is only 7 inches. The decision rule puts 87.5 and 69 percent of the farm in wheat in these two respective states. Consequently, we see that the farm is heavily planted to wheat even with as low a price as $3.10 per bushel.

Following the computed decision rule will ultimately reduce the depth of topsoil to such a shallow layer that normal tillage operations will start mixing the subsoil into the existing topsoil and tend to dilute the organic matter content. Average depth of topsoil in the study area was about 18 inches in 1960 (Pawson, et.al.), so it will take many more years to lose enough soil to create this situation where subsoil is mixed into the topsoil. A rough calculation suggests about 400 years to go from 18 to 6 inches of topsoil when following the decision rule for $3.10 wheat, and about 330 years when following the rule for $4.20 wheat. Under a time span of this length, additional topsoil might be formed while this relatively intensive cropping with wheat is taking place.

Nevertheless, a model which assumes a relatively shallow topsoil is of interest for farms and parts of farms where the topsoil is already thin. Many of the upper slopes of the hills have 6 inches or less of topsoil now.

A Single State Variable Model

A modified model is formulated under the assumption that the topsoil has eroded away and left only 6 inches. In addition we assume that the tillage operations are to a depth of 6 inches, which incorporates new subsoil material into the layer of topsoil as soil is eroded away. Therefore, high soil losses make it more difficult to build up or increase soil organic matter in the top 6 inches.

The above model for two state variables can be reduced to a single state variable model by a simple relationship between $\phi(u,x,y)$ and $h(u,x,y)$. Since the topsoil will be kept at 6 inches depth by mixing subsoil with topsoil that is eroded away, the percent organic matter in year $t + 1$ is given by

$$(12) \quad y_{t+1} = y_t[6 - \phi(u_t,x_t,y_t)]/6 - h(u_t,x_t,y_t) \; .$$

The term in square brackets expresses the dilution effect on organic matter of soil erosion losses. The above specification does assume that the erosion takes place before the organic matter is lost, i.e., before $h(u_t,x_t,y_t)$ is subtracted, which means a particular definition of the discrete annual time period. For The Palouse, this formulation would make sense if the year were specified to begin in the spring because most soil losses occur during the winter rains.

The state variable x for depth of topsoil is set equal to 6 in (12) which gives a simplified difference equation for changes in the percent organic matter of the soil, namely,

$$(13) \quad y_{t+1} = y_t - g(u_t,y_t) \; ,$$

with $g(u,y)$ defined as losses in organic matter during the year. The specific empirical relationship for (13) is obtained by substitution of (10) and (11) into (12) and rearranging the results to get the general form of (13). The expression for $g(u,y)$ is

$$(14) \quad \begin{aligned} g(u,y) = &- .0452 + .857(10)^{-4}u + .478(10)^{-6}u^2 \\ &+ [.01042 + .435(10)^{-4}u + .2143(10)^{-6}u^2]y \; . \end{aligned}$$

The only modification in the annual net return function $G(u,x,y)$ is to set x equal to 6 which reduces the number of arguments to only two.

The approximately optimal decision rule of this model was calculated by the method given in (Burt and Cumming 1977) and compared with the exact decision rule calculated by a dynamic programming algorithm. The dynamic programming algorithm was used with extremely precise accuracy to insure that any differences in the decision rules would be detected. The discrete intervals of approximation were 0.01 and 0.0001 for the state and decision variables, respectively; both are measured in units of percent. The dynamic programming algorithm also used linear interpolation for values of the present value function between the discrete intervals.

The error in the approximately optimal decision rule was less than 0.5 of one percent of the optimal value of the decision variable (percent of land in wheat) when the state variable was in the interval between 1.0 and 6.0 percent organic matter. These results are for a 6 percent discount rate and a $3.10 wheat price in 1978 dollars. The error was somewhat larger when the state variable was less than 1.0; for example, the errors were 0.7 and 1.2 percent of the optimal value when soil organic matter was 0.9 and 0.8, respectively. But this largest percentage error for organic matter at 0.8 was only 0.2 percent of the land area in wheat in obsolute terms, clearly trivial and meaningless in a practical sense.

We conclude that the approximately optimal decision rule is very accurate in this soil conservation application. Comparable results should be obtained in other dynamic optimization problems where the state variables change slowly and smoothly over time, in particular, good results should be typical for economic applications to soil conservation.

The optimal decision rule is given in Table 3. The equilibrium state for organic matter is 2.885 percent and the optimal percentage of land in wheat at the equilibrium state is 56. Annual soil losses would be 2.9 tons

Table 3

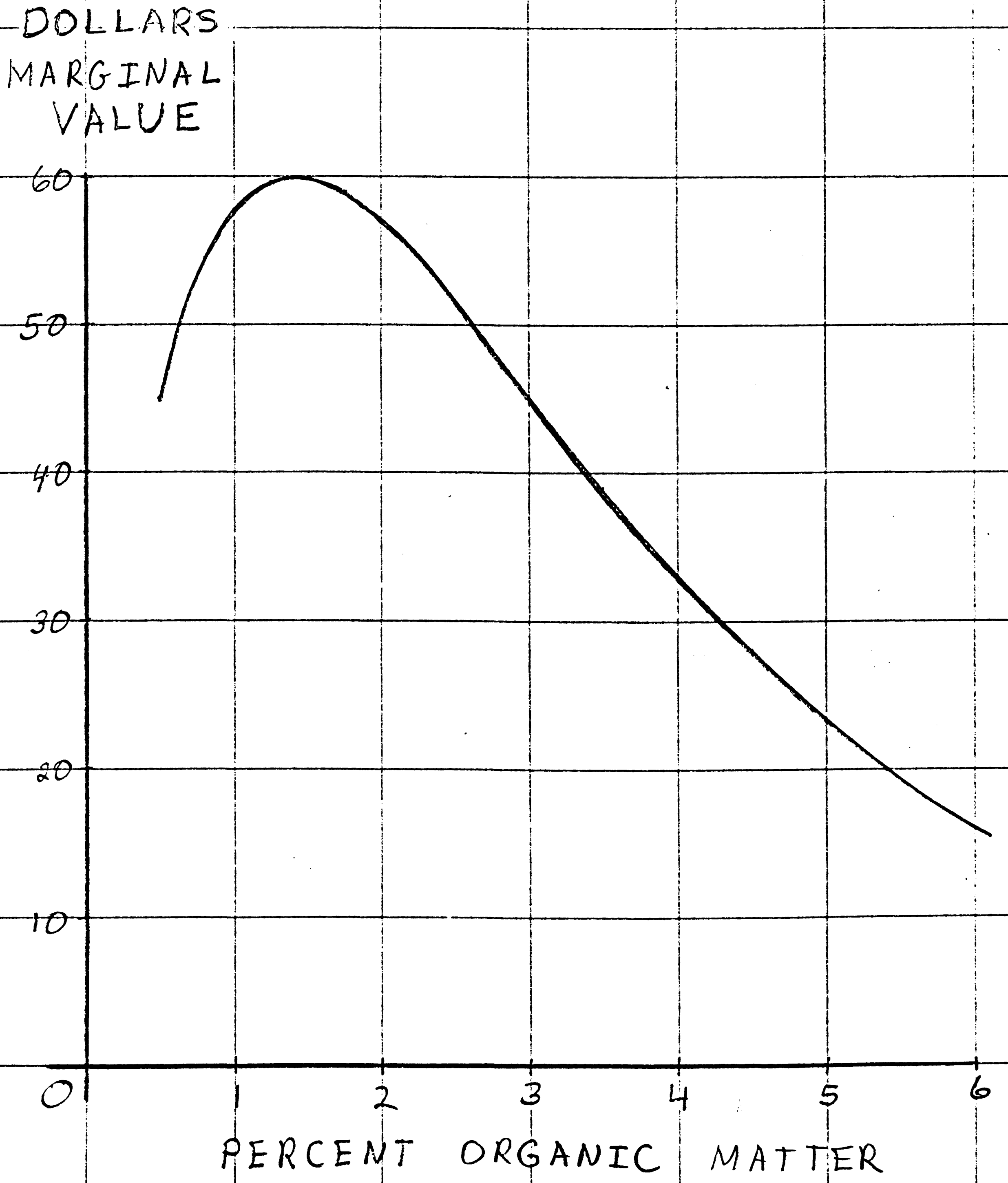
Single State Variable Decision Rule

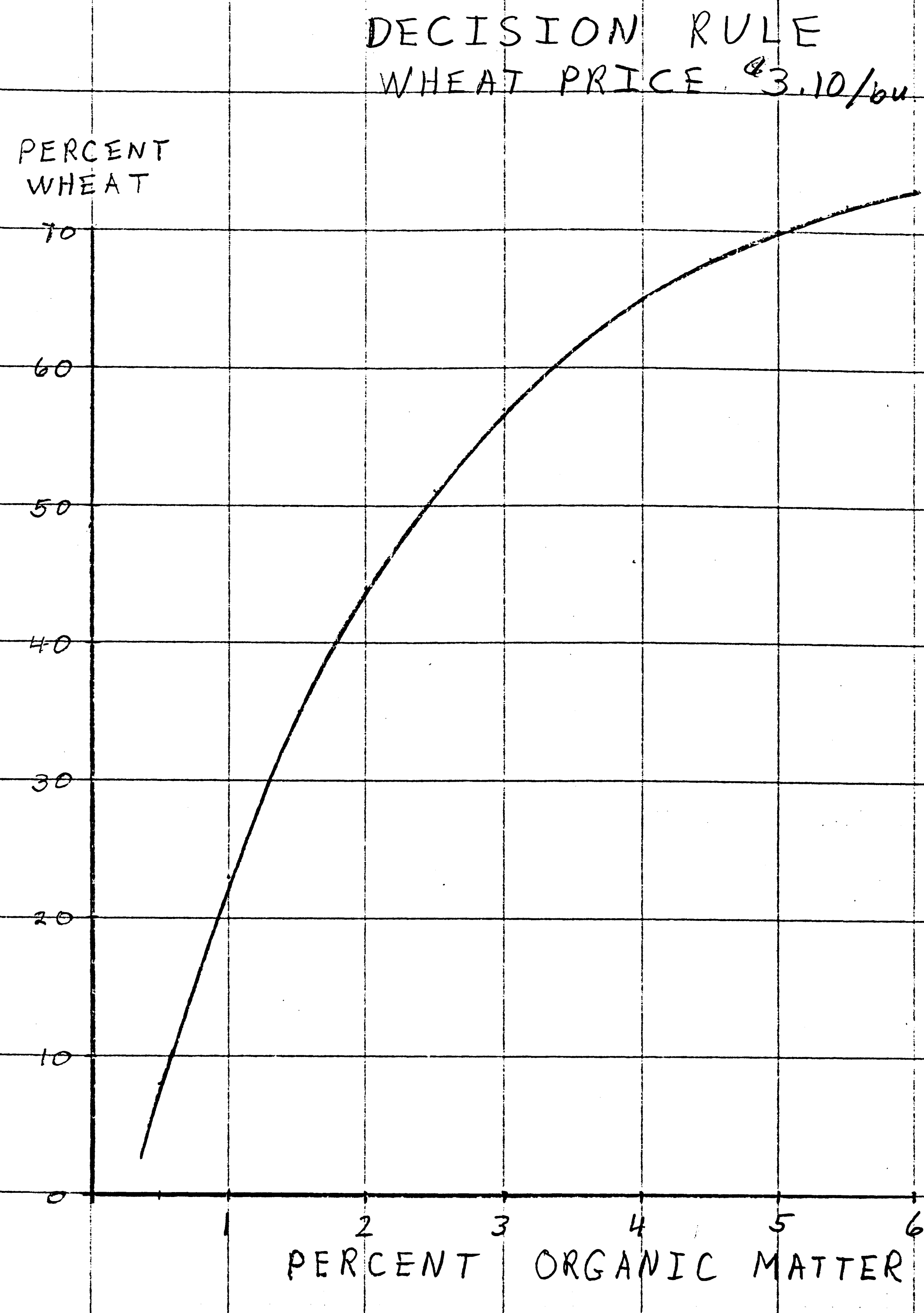
and Marginal Values of Organic Matter[1/]

Organic Matter	Optimum Wheat Area	Marginal Value Organic Matter[2/]
(percent)	(percent)	(1978 dollars)
0.50	8	45.03
0.75	16	53.14
1.00	23	57.72
1.25	29	59.75
1.50	35	59.98
1.75	40	58.89
2.00	44	56.97
2.25	48	54.52
2.50	51	51.48
2.75	54	48.41
3.00	57	45.19
3.25	59	42.04
3.50	61	38.92
3.75	63	35.91
4.00	65	33.07
4.25	66	30.39
4.50	68	27.85
4.75	69	25.48
5.00	70	23.30
5.25	71	21.24
5.50	72	19.37
5.75	72	17.65
6.00	73	16.12

1/ Wheat price in 1978 dollars was $3.10 and the discount rate was 6 percent in the analysis.

2/ Marginal discounted value of net returns associated with an increment to organic matter at the beginning of an infinite planning horizon.


DOLLARS
MARGINAL
VALUE
60
50
40
30
20
10
0
1
2
3
4
5
6
PERCENT ORGANIC MATTER


DECISION RULE
WHEAT PRICE $3.10/bu
PERCENT WHEAT
70
60
50
40
30
20
10
0
1
2
3
4
5
6
PERCENT ORGANIC MATTER

per acre in the equilibrium state which implies an inch of soil loss about every 45 years.

Marginal values associated with an increment to organic matter at the beginning of an infinite planning horizon are given in the last column of Table 3. These values would be for a Lagrange multiplier in a Kuhn-Tucker theory framework (Burt and Cummings 1970) or continuous time control theory model (Hadley and Kemp). In a dynamic programming model, these values are the slope of the functional equation (Burt and Cummings 1977, Appendix).

Note how these marginal values first increase at low levels of organic matter, reach a maximum at about 1.5, and then decline monotonically. This is the same structure as the marginal curve to a classic physical productivity curve from the theory of the firm. In fact the integral of the marginal curve is sigmoid in shape with an inflection point at about 1.5 percent organic matter. These fairly high marginal values in Table 2 illustrate the value of organic matter in a farming system even though quite large amounts of inorganic fertilizer, particularly nitrogen, are used.

When wheat price is increased to $4.20 per bushel in 1978 dollars, the decision rule hits the upper boundary of 87.5 percent wheat if organic matter is greater than or equal to 1.5 percent. Even at 1.0 percent organic matter, the optimal percent of the farm to plant to wheat is 75. The equilibrium state of organic matter is only 2.15 percent compared to 2.89 when the wheat price was $3.10 instead of $4.20. The more exploitive decision rule under a higher price of wheat substantially depresses the long-run level of organic matter. An inch of soil is lost about every 28 years, and it is this relatively heavy soil loss in association with the dilution effect of the subsoil which depresses organic matter in the soil.

Agricultural Policy Implications

The results of this study demonstrate that relatively high grain prices exacerbate soil erosion problems, a proposition long held by economists writing on the economics of soil conservation (see Bunce or Wantrup). Many of the agricultural policies since World War II have not made any differentiation among soils and their vulnerability to erosion. Some of our policies have encouraged summer-fallow, and even summer-fallow in two consecutive years, which is widely known to increase wind and water erosion, as well as directly accelerate organic matter losses.

If grain price support programs are going to be used as an indirect income subsidy policy, special measures should be taken to substitute another kind of subsidy in high erosion risk areas. Maybe farmers living in these areas can have their subsidy hidden in special price supports for relatively soil conserving crops and be excluded from the price subsidy on grains. It does not make sense to have farmers on these highly vulnerable soils planting a large part of their farms to grain because of a price support program, and in addition, they are encouraged into such practices as summer-fallow to get their yield base higher so their subsidy is proportionally larger.

The issue of externalities and social costs of sedimentation and pollution in streams has been purposely avoided in this study. But insofar as soil losses impose these additional costs on society, there exists an incentive for government to subsidize soil conservation measures and/or penalize farming systems which are more erosive on the soil.

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