Soil conservation
C

1980

University of Idaho

DEPARTMENT OF AGRICULTURAL ECONOMICS
College of Agriculture
University of Idaho
Moscow, Idaho 83843

DEVELOPING A SOIL LOSS DAMAGE FUNCTION:

DOES EROSION PAY?

by

David John Walker

A.E. Research Series No. 231

Presented as a selected paper at the annual meeting of the Western Agricultural Economics Association, Las Cruces, New Mexico, July 21, 1980.

David J. Walker is an Assistant Professor, Department of Agricultural Economics and Applied Statistics, University of Idaho. The contribution of Charles L. Peterson in providing field data on minimum tillage is gratefully acknowledged.

Developing a Soil Loss Damage Function:

Does Erosion Pay?

Abstract

A methodology is presented for developing a soil loss damage function to measure the on-site damage from soil erosion resulting from agricultural practices. The soil loss damage function is applied to evaluate a conventional farming practice and a conservation practice in the dry land wheat area of Idaho and Washington.

Developing a Soil Loss Damage Function:
Does Erosion Pay?

Soil erosion and the resulting sediment load in water courses have been recognized in the United States for more than forty years as an environmental and resource problem. The formation of the Soil Conservation Service, a branch of the USDA, in 1935, officially denotes public concern over the problem of soil erosion on the nation's land resource base. This paper attempts to develop a soil loss damage function which allows the evaluation of alternative tillage systems for controlling erosion, taking into account yield damage from cumulative soil loss.

Nature and Extent of Soil Loss

Through his use of the land, man exposes the soil surface to the erosive forces of water and wind. According to one estimate [Pimental] at least a third of the topsoil on U.S. croplands has been lost in the last 200 years. The dominant form of soil loss is from water runoff, although wind erosion, while generally less of a problem, can be severe, particularly in semi-arid regions. This paper will concentrate on soil loss due to water erosion on agricultural land. According to a recent estimate by the U.S. Department of Agriculture, sheet and rill erosion from cropland amounts to almost 2 billion tons annually. About half of this soil loss occurs on land where the erosion rate exceeds the "tolerable rate" of 4 to 5 tons per acre per year [USDA - RCA, p. 15]. The long term productive potential of these lands is being impaired by the excessive erosion.

Even before erosion reaches the point where the topsoil has been stripped from a field, the cumulative effect of erosion is evident in reduced crop yield. The reduced yields are partly due to the loss of essential nutrients. The selective erosion of nutrients and organic matter means poorer quality crops and lower yields. As erosion exposes the subsoil to cultivation, yields decrease for another reason. The subsoil generally has a more blocky structure than topsoil and produces a rougher seedbed to the detriment of germination and yields.

Severely eroded soil suffers from moisture deficiency. Subsoil, because it does not contain as much organic matter as topsoil and has small particle size, is less permeable to water infiltration and is less capable of storing moisture. Therefore, runoff is greater and with less moisture in the soil available for crops, yields suffer. This analysis assumes that the effect of cumulative soil loss on soil productivity can be estimated with a yield function relating crop yield to topsoil depth.

Conservation Programs and Continued Soil Mining

The Soil and Water Resources Conservation Act and the Rural Clean Water Program, both enacted in 1977, reaffirm that the United States is committed to promote programs and policies for conserving the soil and water resources of the nation. Under this new legislation, as in the past, the conservation effort will stress educational programs with technical assistance about erosion control practices and cost-share assistance for farmers who adopt recommended practices. The new legislation provides additional guidance and funding.

After more than forty years of effort, the average annual rate of soil loss has been reduced, but erosion still exceeds the recommended level for preserving the long run productivity of the soil resource on 97 million acres [USDA - RCA, p. 6]. Apparently some farmers continue to "mine" the soil by employing erosive farming practices which offer high yields currently, but because of cumulative soil erosion, diminish the future productivity of the soil.

Perhaps one reason why more progress has not been made in reducing soil erosion is that many conservation practices appear to be more costly than conventional practices, at least from a short run perspective. Higher costs may result from installing and maintaining structures like terraces, from farming operations such as contour plowing, or from employing more fertilizer and pesticides with reduced tillage practices. Other conservation practices impose yield penalties such as grassed waterways which take land out of production and some no-till methods which may result in reduced germination or poor stands due to weeds, plant disease, or insects. Some practices for reducing soil erosion may impose a double penalty on farmers in the form of lower yields and higher costs. These adverse impacts on short run profits dissuade farmers from adopting soil conserving practices.

There is little research data available which quantifies the cost of not controlling erosion, the cost associated with diminished productivity and declining yields in the long run from cumulative soil loss.[1/] This research proposes a methodology for developing and evaluating a damage function from cumulative soil erosion.

Soil Loss Damage Function

The private economic damage function proposed in this approach por-

---

[1/] This cost of not adopting conservation practices becomes a benefit in the form of yield damage avoided if soil conserving practices are implemented.

trays the economic consequences for the farmer from employing a prevailing erosive practice as opposed to a safe practice. A safe practice results in a rate of soil loss not greater than the tolerable rate or "T" value recommended by the Soil Conservation Service for maintaining the long run productivity of the particular soil type. Presumably, with a safe practice, production of the crop could be secured each year indefinitely without depleting the soil resource, resulting in a sustained yield situation. This safe practice serves as a basis for comparison against which other practices can be evaluated.

The proposed soil loss damage function estimates the present value at the end of the current crop year of the private costs and benefits accruing over a relevant time horizon from choosing a conventional erosive practice for producing a crop over a safe practice in the current year.

$$\delta_t = P \times [Y_e (D_{t-1}) - Y_s (D_{t-1})] - (C_e - C_s) - \sum_{i=t+1}^{T} \frac{P \times [Y_s (D_{t-1}) - Y_s (D_t)]}{(1+r)^{i-t}} ,$$

where: δ_t = the value of the damage function in year t, i.e. the private economic value of choosing the erosive practice over the safe practice in year t;

P = price of crop;

Y_e = crop yield with erosive practice as a function of topsoil depth;

Y_s = crop yield with safe practice;

D_t = topsoil depth at end of year t;

C_e = variable cost of crop production with erosive practice;

C_s = variable cost of crop production with safe practice;

T = number of years in time horizon;

r = real private rate of discount.

This specification of a damage function takes into account the following private costs and benefits of choosing the erosive practice.

A. $P \times [Y_e (D_{t-1}) - Y_s (D_{t-1})]$: measures the value of any yield differential between the erosive and safe practices. If the erosive practice is higher yielding, this component in the equation will be positive, a benefit to the farmer from choosing the erosive practice. If the safe practice is higher yielding, this expression will be negative implying a cost from choosing the erosive practice.

B. $-(C_e - C_s)$: reflects any difference in production cost between the two practices. Any saving in fertilizer cost with the safe practice as a result of reduced runoff and lower nutrient loss would be taken into account here. Depending on which practice entails the higher variable costs, this term will be positive or negative implying a benefit or cost from choosing the erosive practice.

C. $-\sum_{i=t+1}^{T} \frac{P \times [Y_s (D_{t-1}) - Y_s (D_t)]}{(1+r)^{i-t}}$: captures the present value of the detrimental effect on future yields[2/] over the relevant time horizon due to soil loss resulting from the use of the erosive practice in the current year. This term always has a negative value since it measures the on-site damage from soil erosion and is a cost to the farmer from choosing the erosive practice.

The algebraic sum of these cost/benefit components determines the present value to the farmer of the economic consequences of choosing the erosive practice in the decision year. If $\delta_t > 0$, the farmer will gain in this private accounting stance from employing the erosive practice in year t and

---

[2/] The yield damage resulting from the decrease in topsoil depth with the erosive practice is evaluated in terms of the safe practice because that practice is the basis for comparison.

the economic incentive would encourage "mining" the soil. If $\delta_t < 0$, the farmer would incur economic damage from selecting the erosive practice in year t and the private economic incentive would encourage conserving the soil.

Since cropping decisions are made annually, the damage function is evaluated on an annual basis. The economic value of choosing an erosive practice over a safe practice is projected for each year in the farmer's planning horizon. In this projection, yield estimates for both erosive and safe practices could incorporate anticipated trends for technological innovation. Any increased production costs associated with the adoption of yield augmenting technology could also be factored into the soil loss damage function projections. In this manner, the soil loss damage function provides a general and flexible framework for evaluating the choice of tillage practice and the consequences of that decision on future productivity and income as a result of soil loss.

As structured, the proposed soil loss damage function exhibits several interesting properties which conform with empirical observation of farmer behavior, suggesting that such a damage function may be useful in understanding farmer decisions regarding soil conservation. The damage function would assume a higher positive value as: (1) the yield of the erosive practice increases relative to the yield of the safe practice, (2) the cost of the safe practice increases relative to the cost of the erosive practice, (3) the price of the crop increases, and as (4) the rate of discount increases. Accordingly, any of the following would reduce the incentive for adopting conservation practices and could potentially encourage mining of the soil: (1) a high yield advantage for erosive tillage practices over conservation practices, (2) a high cost penalty for conservation practices,

(3) little concern for future productivity as reflected in a high discount rate applied to future yield penalties from soil loss, (4) rising crop prices.

The damage function would assume a smaller algebraic value as the yield decline from soil erosion increases and as the planning horizon of the farmer expands. These properties give rise to the following observations. Because the yield damage with further soil loss increases at shallower topsoil depths [Pawson], the economic incentive for continued use of erosive practices decreases as erosion proceeds. Starting with a deep topsoil base, and thus small yield decline from erosion, the value of δ may be positive, providing an economic incentive to mine the soil initially. However, as topsoil is lost and the yield decline increases, the value of δ could become negative, encouraging the farmer to switch over to a safe, conservation practice at some point in time. Finally, an informational program to heighten the concern of farmers for future generations that would expand the relevant time horizon of farmers, would encourage soil conservation.

An Application

In applying the soil loss damage function to an actual cropping situation, a safe practice is compared with an erosive practice currently in use. The comparison is a test of the relative private profitability of the erosive practice. Does the short term net income advantage often associated with erosive practices prevail or does soil loss sufficiently erode the long term productivity of the soil that the short term gain is offset?

For this example the damage function will be applied to the annual cropping area of the Palouse in the states of Idaho and Washington. In the Palouse the major crop, winter wheat, is often grown in rotation with dry peas. The soils are loessial in origin, deposited by the wind in undulating hills which resemble sand dunes in appearance. In this hilly region slopes as steep as 50% are often cultivated. The average precipitation of 22 inches per year is sufficient to allow annual cropping but the erosion hazard is great with average annual soil loss of 14 tons per acre [USDA, 1978]. Losses up to 40 tons per acre have been measured on steeper slopes. The greatest danger from erosion occurs between September and March when over 70% of the annual precipitation occurs. When warm spells or chinooks are accompanied by melting snow or rain on previously frozen ground, soil loss is extensive in the form of rill erosion. The rilling process is exacerbated by excessive runoff due to frozen soil beneath the surface which inhibits water infiltration. At these times the young, fall seeded, wheat plants do not provide much retention for the eroding soil.

One possible solution for reducing erosion under these conditions is to plant wheat directly in the stubble from the preceding crop. This practice requires some form of minimum tillage or no-till practice for seeding wheat in the fall. One promising minimum tillage system (mintill) is the chisel-planter developed at the University of Idaho.[3/] This system which combines shallow chisel plowing with fertilization and seed drilling in one operation, meets the requirement for a safe practice on most slopes in that measured soil loss is reduced to 2 to 3 tons per acre or less.

Costs with the mintill system compare favorably with conventional tillage (contill) costs. Mintill saves labor, fuel, and equipment expen-

---

[3/] Charles L. Peterson and Edwin Dowding of the Department of Agricultural Engineering have developed a prototype which has been undergoing field testing.

ses but entails additional expense for weed control. On balance mintill involves slightly lower costs, $127 per acre for wheat in a wheat-pea rotation, than conventional tillage, $128 per acre. Based on preliminary field trials there is an offsetting yield penalty with mintill. Because of poorer tilth of the seedbed, mintill yields were observed to be 3% below conventional yields. Considering all factors, conventional tillage offers a current profit advantage over mintill.

The following assumptions were employed to illustrate the soil loss damage model: (1) The farmer's time horizon initially is 75 years. This period includes 25 years of his own operation plus 50 years during which his son and then his grandson would be operating the farm. (2) A real private rate of discount of 4% is appropriate for calculating present value. (3) Wheat production is used to compare the two tillage systems resulting in a soil loss of 15 tons per acre with conventional tillage and 2 tons per acre with mintill. (4) The price of wheat is $4.00 per bushel. (5) The appropriate yield function relating wheat yield, y, and topsoil depth, x, is asymptotic based on nonlinear regression analysis [Harker, et. al.]; $y = 36.44 + 47.01\ (1 - e^{-.09864x})$ (see Figure 1). This function exhibits increasing yield damage with further soil loss at shallow topsoil depths. (6) The rate of soil regeneration is negligible, thus net soil loss is equal to the gross erosion rate. Various estimates of the soil formation process assess the length of time required to generate an inch of topsoil between 300 and 1,000 years. A rate of soil loss of 15 tons per acre per year will remove an inch of topsoil in just 10 years.

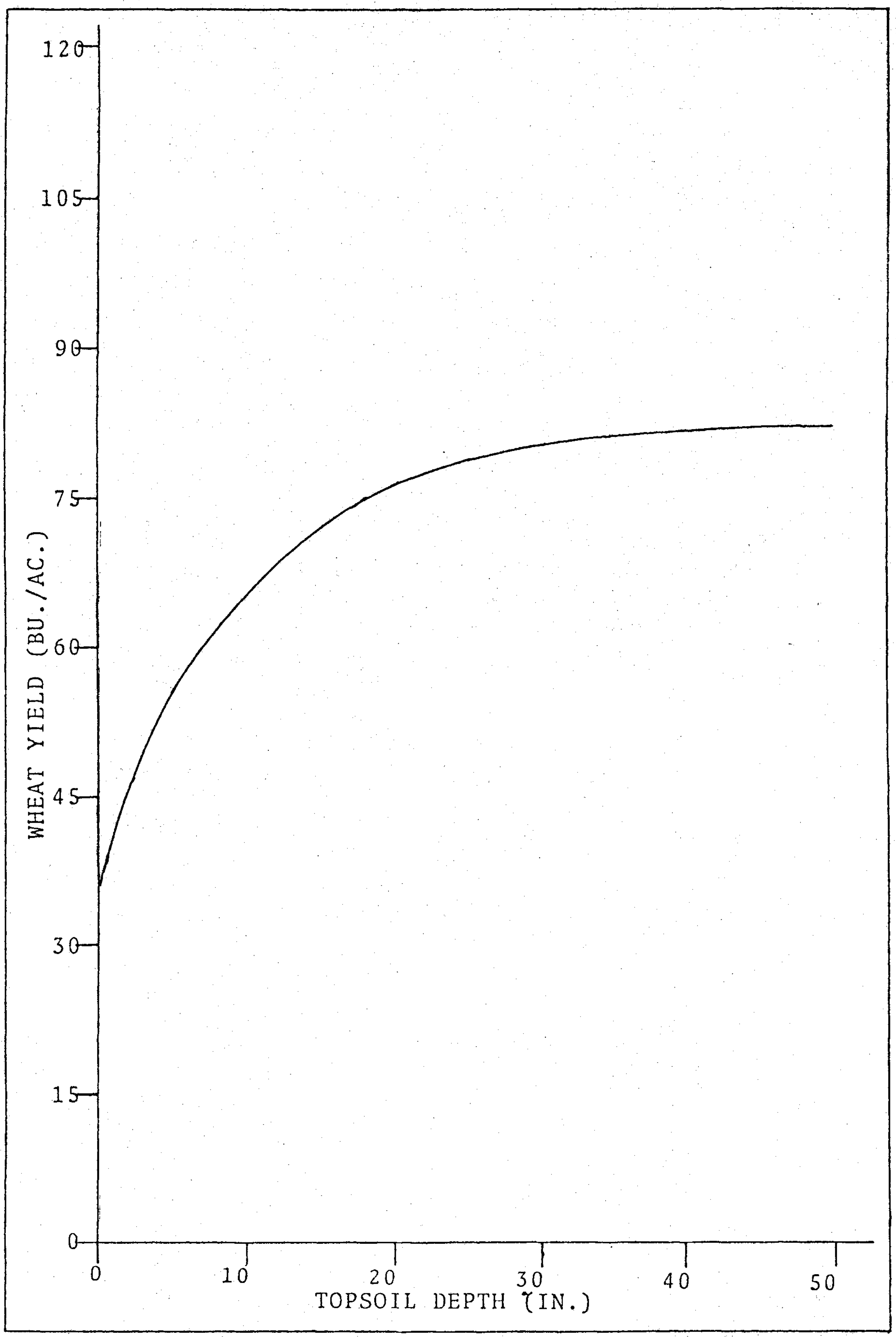

Figure 1: Estimated Effect of Topsoil Depth on Wheat Yield
for Some Common Palouse Soils

By comparison, soil formation is insignificant.[4/] (7) The effect of technological advance on yields is difficult to anticipate. For simplicity in this first application of the soil loss damage function, technology is assumed to augment wheat yields by the same amount for both conventional tillage and minimum tillage regardless of topsoil depth.

Preliminary results with the damage function model indicate that on some soils, conventional tillage appears to be more profitable than mintill from a short run perspective but is unprofitable comparatively speaking when the long run yield damage is considered. On a soil with a current topsoil depth of 12 inches which is typical of the Palouse soil type, there is a short run profit advantage of \$7.29 with conventional tillage. A farmer considering only the short run would be inclined to mine the soil and choose the more erosive but more profitable conventional tillage. Considering the long run perspective, the present value of the yield damage over the time horizon from erosion with conventional tillage in the current year is \$11.66. The value of the damage function is $\delta_1 = -\$4.37$. On balance, in choosing the erosive practice in year 1, the farmer would lose \$4.37 per acre (Table 1). It would pay to adopt the conservation practice immediately on the shallow topsoil.

[4/] Strictly speaking, in this case, the safe practice will not preserve productivity indefinitely because the rate of erosion, while slight, exceeds soil regeneration. The rate of decline in topsoil and yield will be slow, however, with the safe practice. A slightly more complex form of the damage term in item C, page 5, was used to capture the diminution of topsoil depth with the safe practice in this application:

$$- \sum_{i=t+1}^{T} \frac{P \times [Y_s (D_{i-1,\ t-1}) - Y_s (D_{i-1,\ t})]}{(1+r)^{i-t}} ,$$

where Dn,m = projected depth of topsoil at the end of year n after m years of soil loss with the erosive practice followed by n - m years of reduced soil loss with the safe practice.

Table 1: Typical Palouse Soil (current topsoil depth - 12 inches)

Year	Contill Yield(bu/A)	Current Contill Advantage($/A)	Present Value LR Yield Damage($/A)	Net Value($/A)
1	69.06	7.29	11.66	-4.37
10	67.72	7.13	12.41	-5.28
25	65.21	6.82	13.36	-6.54

With a deeper topsoil, a different picture emerges. On a Thatuna soil with typical topsoil depth of 21.5 inches, the short run profit advantage is $8.34 with conventional tillage. In the first year of the simulation, the present value of the long run yield damage is $4.57 so that the value of the damage function is δ_1 = +$3.77 (Table 2). Even considering the long run yield damage there is an economic incentive to mine the soil by choosing the more erosive conventional tillage. Yield damage due to erosion from a deep topsoil base is not so serious as indicated by the shape of the yield function. The model evaluates the damage function annually, as a farmer would make annual cropping decisions, taking into account the effect on long run yields from the additional erosion resulting from the choice of the conventional system in year t.

The evaluation of the damage function in subsequent years indicates that the value of the immediate profit advantage declines because of the decline in soil productivity with erosion and that the present value of the long run yield damage increases due to the increasing severity of the yield decline with cumulative soil loss. However, throughout the 25 year operating period of the farmer, $\delta_t > 0$ indicating the private economic incentive to choose the erosive conventional system and mine the soil (see

Table 2: Typical Thatuna Soil (current topsoil depth - 21.5 inches)

Year	Contill Yield (bu/A)	Current Contill Advantage ($/A)	Present Value LR Yield Damage ($/A)	Net Value ($/A)
1	77.81	8.34	4.57	3.77
10	77.29	8.27	4.86	3.41
25	76.31	8.15	5.23	2.92
		Second Generation		
1	76.23	8.15	5.85	2.30
10	75.56	8.07	6.22	1.85
25	74.31	7.92	6.70	1.22
		Third Generation		
1	74.22	7.91	7.48	0.43
2	74.13	7.90	7.54	0.36
3	74.03	7.88	7.59	0.29
4	73.94	7.87	7.64	0.23
5	73.85	7.86	7.70	0.16
6	73.75	7.85	7.75	0.10
7	73.65	7.84	7.81	0.03
8	73.56	7.83	7.86	-0.03
9	73.46	7.82	7.91	-0.09
10	73.36	7.80	7.96	-0.16
11	73.26	7.79	8.01	-0.22
12	73.16	7.78	8.06	-0.28
13	73.06	7.77	8.11	-0.34
14	72.95	7.75	8.15	-0.40
15	72.85	7.74	8.20	-0.46

Table 2). The economic incentive to choose conventional tillage over the safe practice continues during the 25 year operating period for the farmer's son where $\delta_t > 0$.

In the 8th year of the grandson's operation $\delta_t < 0$ revealing that the present value of the long run yield damage from selecting the conventional system for one more year exceeds the current profit advantage with that system. The switchover point to the safe practice occurs 58 years into the simulation because at that time topsoil depth has declined to the point where further soil loss with the more erosive practice would impose ever increasing yield damage in that steep segment of the yield function. This simulation with the soil loss damage function model is quite realistic in that many farmers do not exhibit an interest in conservation practices until their topsoil has been eroded to shallow depths through many years of conventional tillage.

Conclusions

Analysis with the damage function indicated that on the shallow soil it was economic to adopt the conservation practice immediately. With the deeper topsoil it didn't become economic to abandon the erosive practice for the safe practice until erosion with conventional tillage had progressed for 57 years, reducing topsoil below approximately 16 inches.

There are several potential uses for this type of analysis. For the present policy emphasis on voluntary conservation programs to succeed, the private profitability of soil conservation must be demonstrated. The results from the damage function analysis could be used as an educational tool to illustrate the cost of erosion and to show that conservation can pay the farmer if long run yield damage is considered. As a research tool, the damage function model could be used to develop practices which pay off sooner, and to eliminate practices which may never pay off in the foreseeable future. Finally, the estimate for on-site damage from soil loss could be combined with estimates from an off-site damage model to determine the optimal rate of soil loss in a region.

Selected References

Barrows, Harold L. and Victor J. Kilmer. "Plant Nutrient Losses by Water Erosion." Advances in Agronomy 15 (1963): 303-316.

Harker, J. Michael, D. J. Walker, E. L. Michalson, J. R. Hamilton, F. Wetter. "Wheat Yield and Topsoil Depth: A Tentative Assessment for the Palouse." University of Idaho, Department of Agricultural Economics and Applied Statistics, unpublished.

Pawson, W. W., O. L. Brough Jr., J. P. Swanson and G. M. Horner. "Economics of Cropping Systems and Soil Conservation in the Palouse." Idaho Agricultural Experiment Station, Research Bulletin No. 2, Moscow, 1961.

Pimentel, David et. al. "Land Degradation: Effects on Food and Energy Resources." Science 194 (October 1976): 149-155.

USDA. Palouse Cooperative River Basin Study. USDA, Soil Conservation Service, 1978.

USDA. Summary of Appraisal, Soil and Water Resources Conservation Act (RCA), Review Draft, 1980. USDA - Soil Conservation Service, 1980.