Soil Erosion and Productivity: What is the Relationship?

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Soil erosion decreases soil productivity by lowering crop yields and raising fertilizer and lime application requirements. The report discusses how these effects occur and how they may be estimated. The overall effect of another 100 years of erosion at 1982 levels will lower the productivity of the Nation's food and fiber sector by 3.6 percent. This overall figure masks wide variations in impacts among soils and regions; many soils will be unaffected, while a few soils will lose much of their productivity. Decision-makers may use this variation as the rationale for targeting erosion prevention expenditures to those acres that are most significantly impacted by erosion, unless there are some offsite pollution or other non-productivity reasons for preventing erosion on the other soils.

WHAT ARE THE EFFECTS OF EROSION?

Erosion is a natural process that moves soil by water or wind. As land is farmed, erosion can accelerate, decreasing soil productivity by thinning and modifying the plant root zone and by removing nutrients and organic matter. Sheet erosion removes a thin, fairly uniform layer of soil when rainwater runs across exposed soil. Rill erosion occurs when runoff water erodes small channels no more than a few inches deep. When wind picks up loose soil particles and carries them away, the result is called wind erosion. Cropland affected by wind erosion tends to be in different regions than the cropland affected by sheet and rill erosion. For example, the Southern Plains and Mountain States experience primarily wind erosion. The humid Eastern States usually encounter relatively more sheet and rill erosion.

Erosion changes in the root zone, which may be gradual, depend on how much the existing plow layer differs from the lower soil. If the differences are great, then plowing will incorporate the lower layers and will gradually change the texture and chemical properties of the plow layer. These changes may progressively decrease the soil's moisture-holding capacity and intensify toxicity problems. Soil structure changes caused by erosion may also reduce moisture infiltration, thus making less water available to the plants, which may reduce yields.

Erosion reduces farm income because fertilizers and lime washed away with the eroding soil material must be replaced. Fertilizer and lime applications may also increase to offset changes in soil chemical properties caused by mixing subsoil into the plow layer.

Erosion may disrupt and delay agricultural operations, damage plants by washouts or by sediment deposits, increase production costs because of replanting and repeating certain practices, and cause gullies that bisect fields. This report, however, estimates only the productivity effects of soil loss from wind, sheet, and rill erosion (not including ephemeral or gully erosion). We are defining the productivity effects as the sum of the yield losses and the cost increases for fertilizer and lime that are caused by erosion. Our limitation to the soil productivity impacts onsite excludes substantial costs; other studies forecast greater offsite erosion damages than erosion-impaired productivity (1, 4).

Erosion may also change the variability of crop yields. The effect of erosion may show up in the soil's increased vulnerability to drought, with yield losses that are larger than losses in previous drought periods.

Excessive soil erosion slowly, but steadily, reduces farm income. The effect may be so slow as to go unnoticed either because the topsoil is very deep or because the erosion rate exceeds the natural regeneration rate of topsoil by only a small amount. Excessive erosion, however, may eventually reduce crop yields to the point that continued crop production will become impractical, forcing the grower to retire the land to permanent pasture or some other lower valued land use.

The definition of "excessive" erosion revolves around the concept of the soil loss tolerance level, the T-value. For 71 percent of the Nation's cropland, the T-value is 5 tons of erosion per acre per year (t/a/yr). Other cropland has lower T-values, some as low as 1 t/a/yr. The T-value is the maximum rate of annual soil erosion which may occur and still permit a high level of crop productivity economically and indefinitely. (5)[1/] By definition, erosion below the T-value has no effect on productivity onsite, even though it may have offsite effects.

Table 1 shows the regional distribution of the acreage of soils with erosion rates above and below the T-value. We have combined the wind erosion estimate with the sheet and rill erosion estimate as published in the 1982 National Resources Inventory (NRI) (7), since the productivity effect of erosion depends on how much soil is eroded away, not on the type of erosion. This addition may bias our results upwards because the estimates of wind erosion are not as reliable as the estimates of sheet and rill erosion:

> "With the Wind Erosion Equation (WEQ), we can estimate the amount of soil moved by wind under specified conditions. Because of soil and crop conditions that the model does not address, we can not have a high degree of confidence in the estimate of the amount that leaves the field." (8).

As this statement implies, the WEQ estimates how much soil is detached by wind forces, but cannot reliably estimate how much of this soil may move only a few feet and may never leave the field. Thus, the total erosion estimate and, so, the erosion effect estimate may be biased upward slightly. Nonetheless, we have used the erosion estimates, the best available, in this analysis as they were published in the 1982 National Resource Inventory (NRI) (7).

1/ Underlined numbers in parentheses cite sources listed in the References section.

HOW ARE EROSION EFFECTS MEASURED?

We multiplied the NRI estimate of current (1982) erosion, if it exceeded the T-value, by an estimate of the effect per ton of erosion on fertilizer use and crop yields. In our computations, the effect per unit of erosion was derived from the Erosion Productivity Impact Calculator (EPIC). The EPIC model is a detailed crop growth simulation model, which its developers continue to improve based on ongoing research. A description of the model as it was configured to derive the present estimates is available in (2). An explanation of the data processing of EPIC simulation results for this study is given in (3).

Table 1--Cropland acreage with erosion above or below the soil tolerance value (T), by region, 1982

Region	Below T-value	Above T-value	Total
		Million acres	
Northeast	11.8	5.5	17.3
Lake States	23.6	20.3	43.9
Corn Belt	46.2	46.2	92.4
Northern Plains	56.8	36.6	93.4
Appalachia	13.6	9.1	22.7
Southeast	11.1	7.1	18.2
Delta	13.4	8.5	21.9
Southern Plains	21.2	23.7	44.9
Mountain	21.8	21.5	43.3
Pacific	16.1	6.6	22.7
United States	235.6	185.0	420.7

Source: (7)

EPIC estimates the long-term effects of erosion, and the model simulations are stretched over 100 years. These EPIC simulations allowed for variations in rainfall from year to year. The pattern of the variation was derived from historical data for each site. We used the accumulated erosion nd yield data from the EPIC simulation runs to determine the yield impact per ton of erosion.

The only crop management variable that was not held constant in the EPIC simulation was the use of fertilizer and lime. A researcher would normally measure the effect of erosion on soil productivity by holding all inputs constant, letting the soil erode, and then measuring the yield decrease over time. However, farmers are likely to adjust their chemical use to replace chemicals washed away with eroding soil. For this reason, the EPIC simulations allowed fertilizer and lime applications to increase to maintain the agronomically optimal fertility. Thus, throughout the following discussion, we will present two parts of erosion's effect on soil productivity, namely the fertilizer cost increase and the yield loss despite the new fertilization rates. The total productivity effect sums these two parts.

These model features combine to limit the results. The EPIC model assumes a constant technology for all years of model simulation. Rather than claiming that EPIC forecasts the 2082 situation, we should describe the EPIC model as simulating 1982 conditions for 100 times sequentially, with each simulation changing the soil conditions slightly for the next simulation. Over the next 100 years, technology will change, of course, so the actual

2082 impacts will differ from the estimates shown here. Nonetheless, the present estimates give an indication of the size of the effect that erosion will have on future productivity.

Erosion effects differ not only by soil texture, slope, rainfall and other physical determinants, but also by the nature of the crop grown and its tillage. We based our computations on the 1982 distribution of crops by region and soil. If one were to assume a different distribution (for example that crops that erode heavily will be grown only on noneroding bottomlands), the impact estimate would, of course, differ from what we show here. This is another limitation of the present results. The Conservation Reserve Program has already removed from production about 26 million acres of the most erodible cropland, at least for the next 10 years. In addition, conservation tillage has been adopted on more acres since 1982. These factors reduce current erosion and thus future erosion impacts. So, our results may overstate the future losses. We will not be able to quantify this overstatement until the 1987 NRI results become available.

Alternative ways of producing these estimates exist, even if one relies on the same data sets. These alternatives will produce slightly different numbers, but none of the alternatives that we investigated gives a significantly different overall result. The estimates in the Second Resource Conservation Act Appraisal (6) are slightly lower, because they were computed for sheet and rill erosion separately from wind erosion, rather than for the total erosion as we did here. Summing both erosion amounts will cause erosion to exceed the T-value on a larger acreage, thus raising the national impact estimate.

WHAT ARE THE RESULTS OF EROSION?

At the national level, the potential loss of cropland productivity after 100 years is about 3.6 percent, resulting in a $3.1 billion production loss for the last year of the simulation (Table 2). This value is based on the difference in crop revenue and production costs, holding the per unit prices of crops and inputs constant at 1982 levels.

Table 2--Change in value of gross product after 100 years of sheet, rill, and wind erosion

Region	Cropland acres	Gross product value change from--			
		Crop yield decrease	Fertilizer compensation		Total
	Million	- - - - -	Percent	- - - - -	Million Dollars
Northeast	17.3	8.2	0.6	8.8	342
Lake States	43.9	3.7	.4	4.1	428
Corn Belt	92.4	3.7	.7	4.4	1,182
Northern Plains	93.4	1.4	.4	1.8	231
Appalachia	22.7	4.8	.7	5.5	261
Southeast	18.2	1.4	.4	1.8	72
Delta States	21.9	1.5	.2	1.7	82
Southern Plains	44.9	2.6	1.6	4.2	303
Mountain	43.3	1.5	.6	2.1	129
Pacific	22.7	1.6	.3	1.9	107
United States	420.7	3.0	.6	3.6	3,137

Table 3 shows how yield loss and additional fertilizer costs are distributed on a regional basis. While the fertilizer cost is almost as large as the value of the yield loss in the Southern Plains, most regions' fertilizer component amounts to less than 20 percent of the total loss.

The total values given for the last year of the simulation do not apply to every year of the simulation. The additional cost component for fertilizer and lime replacement will remain constant through time. However, the yield loss component will increase as a result of the gradual changes in the soil profile, up to the reported loss for the 100th year. We assumed that this change occurs at a constant rate, namely that the yield loss will increase by $26.2 million per year nationally from a loss in the first year of $545.2 million. Table 3 presents the net present value of this increasing stream of costs, discounted at 4 percent.

Table 3--Value of losses from 100 years of erosion

Region	Loss in 100th year			Net Present
	Total 1/	Yield	Fertilizer	Value 2/
	Million Dollars			
Northeast	341.7	316.0	25.7	2,486.6
Lake States	428.2	385.1	43.1	3,318.3
Corn Belt	1,181.9	1,001.4	180.5	10,306.8
Northern Plains	230.6	189.9	40.7	2,113.5
Appalachia	260.8	226.7	34.1	2,167.1
Southeast	71.9	57.6	14.3	689.0
Delta	82.4	70.4	12.0	706.7
Southern Plains	303.0	188.8	114.2	3,908.6
Mountain	129.2	90.8	38.4	1,474.4
Pacific	107.4	91.3	16.1	931.8
United States	3,137.1	2,618.0	519.0	28,102.9

1/ Computed as difference between first and 100th year. 2/ Computed as net present value of 100 yearly losses, discounted at 4 percent.

Tables 4 and 5 separate the yield loss effect from the fertilizer cost increase. These tables show how many acres will be affected in each region.

Well over half of the cropland has yield losses of less than 2 percent under current farming practices and erosion rates (table 4). Almost 40 million acres or almost 10 percent of the cropland will lose more than 8 percent of their crop yields over the next 100 years. The Northeast, Lake States, Corn Belt, and Appalachia contribute two-thirds of the Nation's highest yield loss acres (with 25 percent or more yield loss). In these four regions and in the Southern Plains, more than 10 percent of the region's cropland loses more than 8 percent of its crop yields.

Table 4--Cropland acreage with yield losses if sheet, rill, and wind erosion continue for 100 years, by region and range of loss 1/

Region	Percentage yield losses-- None-1.9	2-7.9	8-24.9	25-49.9	over 50	Total acres
	Million acres					
Northeast	8.2	4.4	3.0	1.5	0.2	17.3
Lake States	17.1	19.2	6.8	.8	.1	43.9
Corn Belt	32.2	49.7	9.7	.7	.1	92.4
Northern Plains	73.3	16.4	3.3	.2	.2	93.4
Appalachian	13.5	5.9	2.4	.5	.4	22.7
Southeast	13.9	3.4	1.0	*2/	*	18.2
Delta States	15.4	5.5	.9	.1	*	21.9
Southern Plains	33.2	7.2	4.0	.5	*	44.9
Mountain	34.3	7.3	1.3	.2	.2	43.3
Pacific	18.9	2.3	.8	.2	.5	22.7
United States	259.8	121.2	33.2	4.7	1.7	420.7
	Percent					
Percentage of total acres	61.8	28.8	7.9	1.1	.4	100.0

1/ Totals may not add due to rounding. 2/ Less than 50,000 acres.

The fertilizer cost effects sum the cost increases in nitrogen, phosphate, and lime that erosion causes (table 5). The percentage cost increase relates the after-erosion cost for fertilizer and lime to the before-erosion cost for those materials only, rather than to the total cost of production. About 40 percent of the cropland will increase those costs by less than 2 percent. However, almost one quarter of all cropland will need a boost of more than 8 percent in its fertilizer and lime costs over the next 100 years. The Corn Belt and Southern Plains regions contain over half of the acres with the highest fertilizer and lime cost increases (with 25 percent or more additional costs). Only in the Southern Plains region will more than 10 percent of its cropland need more than 25 percent additional fertilizer and lime.

Table 5--Cropland acreage with fertilizer and lime cost increases if sheet, rill, and wind erosion continue for 100 years, by region and range of cost increase 1/

Region	Percentage cost increases-- None-1.9	2-7.9	8-24.9	25-49.9	over 50	Total acres
	Million acres					
Northeast	9.3	3.8	3.8	0.3	*2/	17.3
Lake States	13.9	19.4	9.6	1.0	*	43.9
Corn Belt	16.2	44.7	26.3	4.8	0.4	92.4
Northern Plains	33.6	39.3	18.7	1.4	.3	93.4
Appalachian	12.1	6.0	3.2	.9	.5	22.7
Southeast	10.3	6.1	1.2	.7	*	18.2
Delta States	13.9	6.7	.6	.3	.4	21.9
Southern Plains	15.7	11.2	6.4	3.4	8.1	44.9
Mountain	26.0	7.0	7.5	2.5	.4	43.3
Pacific	16.6	3.4	1.8	.7	.1	22.7
United States	167.7	147.7	79.1	15.9	10.3	420.7
	Percent					
Percentage of total acres	39.9	35.1	18.8	3.8	2.4	100.0

1/ Totals may not add due to rounding. 2/ Less than 50,000 acres.

REFERENCES

1. American Agricultural Economics Association, Soil Conservation Policy Task Force. January 1986. Soil Erosion and Soil Conservation Policy in the United States. Occasional Paper No. 2.

2. Putman, John W., and Paul T. Dyke. June 1987. The Erosion-Productivity Impact Calculator as Formulated for the Resource Conservation Act Appraisal. Staff Report AGES861204. Econ. Res. Serv., U.S. Dept. Agri.

3. Putman, John W., Paul T. Dyke, Glen L. Wistrand, and Klaus F. Alt. June 1987. The Erosion-Productivity Index Simulator Model. Staff Report AGES870602. Econ. Res. Serv., U.S. Dept. Agri.

4. Ribaudo, Marc O. Sept. 1986. Reducing Soil Erosion: Offsite Benefits. AER-561, Econ. Res. Serv., U.S. Dept. Agri.

5. Soil Conservation Society of America. 1982. Resources Conservation Glossary. Ankeny, IA.

6. U.S. Department of Agriculture. July 1987. The Second Resource Conservation Act Appraisal. Public Review Draft.

7. __________, Soil Conservation Service. July 1984. Basic Statistics - 1982 National Resources Inventory.

8. __________, Soil Conservation Service. June 1987. Soil and Water Conservation Research and Education Progress and Needs.