The Threat of Soil Erosion to Long-Term Crop Production

W. E. Larson, F. J. Pierce, R. H. Dowdy

Although soil erosion was of concern to George Washington, Thomas Jefferson, and James Madison (*1*), it was not until the early 1930's that the problem was brought to the attention of Congress and the nation. A prime mover in this was H. H. Bennett (*2*), a soil scientist with the U.S. Department of Agriculture (USDA). Bennett was responsible for the establishment of the Soil Conservation Service in 1935.

Summary. National increases in row crops at the expense of hay and pasture crops, particularly on steeper slopes, have made the control of erosion a difficult prospect. Management practices that fit the various field conditions are needed to accomplish effective erosion control. These measures should be selected on the basis of soil characteristics, landscape type, and the amount of ongoing erosion. The maintenance of a cropland base adequate to our needs must be a primary national goal.

Since 1928, when the first estimate of the amount of erosion occurring nationally was published (*3*), there have been many additional estimates (*4*). The bases of these estimates, however, are obscure, inadequate, and variable. Thus the debate as to whether soil erosion on cropland has increased or decreased since the 1930's cannot be resolved. Instead, we should seek to ascertain the seriousness of current soil erosion with respect to long-term food and fiber production.

Erosion is a group of processes whereby earthy and rock materials are loosened or dissolved and removed from the earth's surface. It includes the processes of weathering, solution, corrasion, and transportation. Before cultivation of crops, erosion was beneficial for the most part, leading as it did to the formation of fertile deltas and valleys. During the period of evolution of the present landscape (Wisconsin to Recent geologic time), erosion may have been cyclic, occurring in a series of cut-and-fill cycles separated by periods of stability (*5*). It is even possible that erosion rates in the geologic past at times exceeded current rates. The fundamental issue today is the sustained acceleration of erosion resulting from human activities.

The Soil and Water Resources Conservation Act (RCA) of 1977 (*6*) and the National Agricultural Lands Study (*7*) have raised serious concern over the degradation of U.S. soil resources. Factors contributing to this concern have been the sharp increase in grain exports during the past decade and the increased area of sloping, marginal, and fragile soils planted in row crops. On the basis of 1977 estimates (*6, 8*), it was concluded in the RCA report that soil erosion is the main conservation problem on about 50 percent of the nation's cultivated cropland. While the RCA study was the most extensive inventory of soil quality and erosion ever completed in the United States, the long-term effects of erosion on crop productivity were not assessed. A recent national workshop sponsored by ten scientific societies cited "sustaining soil productivity" as their first research objective (*9*). They stated the need for studies "to quantify the relationship between plant growth and those soil attributes affected by erosion."

Research to quantify erosion has been based on the physical principle that soil movement occurs in response to forces generated by the flow of water or wind. For movement of soil particulates to occur, a threshold level of energy must be attained. Similarly, a minimum energy level must be maintained to keep the particulates in motion. The amount of erosion, therefore, is determined by the amount of energy available at the soil surface and the energy requirements for dislodging particulates and maintaining flow. These vary by location (climate), surface configuration, soil type, vegetative cover, and landscape. Erosion control practices have been aimed at either minimizing the energy available or maximizing the energy required to dislodge soil particulates. Terracing, contour cultivation, planting of windbreaks, improving the stability of soil aggregates through soil stabilization, crop residue management, and conservation tillage are examples of such practices.

Concern over erosion is universal. There is, however, disagreement as to the extent of erosion, its effects on plant productivity and the environment, and its socioeconomic impacts. This article addresses the threat of erosion to long-term crop productivity.

Soil Layers

Erosion results in both on-site damage to soil and crops and off-site damage in the form of water and air pollution and damage to man-made and natural structures. The degree of damage is determined, to a great extent, by the nature of the soil and its position in the landscape.

The soil is a natural, organized body evolving slowly under the influence of many factors (*10*). The processes of soil formation include the processes of erosion. A soil survives erosion because it is protected or forms as fast as it is dissipated.

A vertical soil profile (Fig. 1) displays layers or horizons with characteristic physical and chemical properties. Soils with similar horizons are grouped into soil series. In a particular landscape, two or more soil series form a soil association (Fig. 2). Soil associations are important in determining optimum land-use patterns for agriculture (*11*).

The profile of a soil provides the key to its vulnerability to erosion. The letters A, B, and C are used to designate soil horizons (Fig. 1). The A horizons lie at or near the surface and are characterized by maximum accumulation of organic matter and maximum leaching of clay materials, iron, and aluminum. The B horizons (subsoil) consist of weathered material with maximum accumulation of iron and aluminum oxides and silicate clays. The C horizons are unconsolidated material underlying the A and B horizons, and are affected relatively little by

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soil-forming processes. Not all horizons are present in all soils, since interactions of the soil-forming processes produce different profiles.

The A horizons of cultivated soils play an important role in controlling water, heat, and gas balances. Plant roots and available nutrients are concentrated in this layer, whose thickness varies from a few centimeters to as many as 50. In many cultivated soils the A horizons have been decreased in thickness or removed by erosion. When tilled, the A horizons may be mixed with the upper B horizons, resulting in a surface soil quite different in texture and other characteristics from that observed in the uneroded condition. This is important since the stability of the soil surface and the rate at which it conducts water affect the amount of erosion that occurs.

Many soils have B horizons that are unfavorable for plant root growth. Among these are horizons with excessive accumulations of clay (argillic), high density and strength (fragic), cement-like qualities (duric), low *p*H (acidic), salt accumulation (salic), and high aluminum saturation. In addition, water permeability is often controlled by the B horizons. Hence, soils with unfavorable B horizon characteristics pose a double threat by increasing the potential for runoff and erosion and by forming a barrier to root development as erosion brings these horizons closer to the surface.

Landscapes

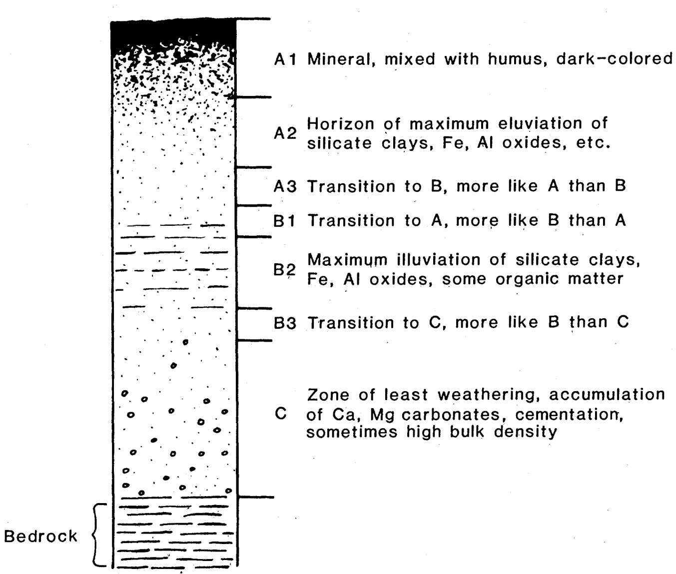
Most cultivated landscapes fall between two topographic extremes. One has small relief, no major surface outlet, and containment of runoff water and transported sediment in depressional areas (Fig. 2A) (*14*). In this landscape very little or no sediment may leave the cultivated area. This topography is common in areas of the north-central United States with glacial-derived soils [for example, Major Land Resource Area (MLRA) 103] (*13*).

The other topographic extreme has distinct slopes and deep incised stream valleys (Fig. 2B) (*12*). In this landscape erosion may be severe and a relatively large amount of the sediment may leave the cultivated area and be deposited on a floodplain or carried far away. Examples of this landscape are the loess hills bordering the Mississippi and Missouri rivers (MLRA's 107 and 134).

Examples of the effect of landscape and soils on the estimated amount of sediment entering a stream channel are given in Table 1 for five watersheds in Minnesota (*15, 16*). The proportion of eroded soil leaving the local area varies from < 1 to 27 percent. The eroded sediment not leaving the local area is deposited somewhere at the toe of the eroded slope, but does not enter the stream. The sediment may be deposited on cropland, wasteland, pasture, or forest land. In the central Corn Belt, much of the sediment eroded from cropland slopes is probably deposited on other cultivated land. Of the sediment in U.S. streams, 59 percent arises from cropland, pasture, rangeland, and forest land; 26 percent arises from stream banks; and 15 percent arises from other sources (*6*).

Eroded sediments from sloping cropland are often of little immediate value, or may be detrimental, when deposited on other croplands. Such sediments may be deposited on soils already deep and highly fertile, and thus add nothing to the productivity of the soil.

Soil management practices should be related to the arrangement of the landscape. The Mount Carroll soils (Fig. 2B)



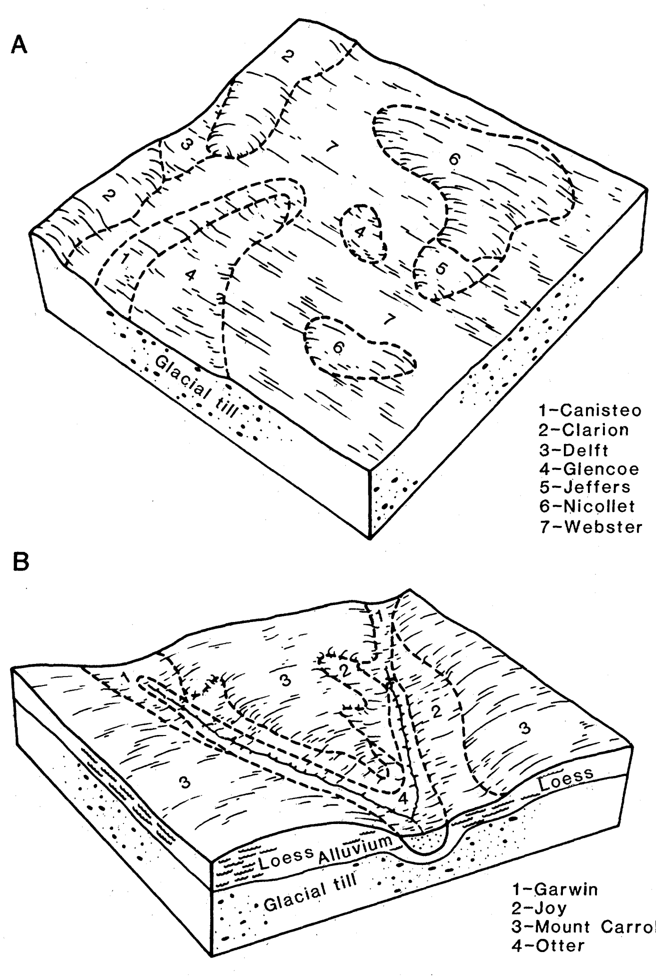


Fig. 1 (left). Theoretical soil profile showing major horizon designations. [Adapted from (*11*)] Fig. 2 (right). Relation of soils, underlying materials, and landscapes in (A) the Webster-Nicollet association (*14*) and (B) the Mount Carroll-Otter-Joy association (*12*).

erode rapidly, and the sediment is likely to be deposited on the colluvial slopes (Joy series) or in the narrow floodplain (Otter series). This landscape is similar to the Root River watershed (Table 1). The arrangement is such that a combination of similar soils can be managed similarly. In such a landscape it is practical to contour and strip-crop to provide some erosion control.

In contrast, the Clarion soils, due to their position in the landscape, have higher erosion rates (Fig. 2A) than the other soils associated with it. The eroded sediment from the sloping Clarion soils is deposited on the Webster or Glencoe areas. This landscape is similar to the Redwood River watershed (Table 1). Because of the complex nature of the topography, it is difficult to use a variety of management practices, and indeed, this usually does not occur. Rather, the farmers arrange their fields in large rectangular blocks and manage all soils alike. Thus the sloping soils may be degrading at a moderate or high rate even though they may constitute only a small portion of the cultivated area.

The difficulty of designing and implementing effective erosion control programs is explained in part by the many different types of landscapes and soils. Methods that will fit the various situations encountered in the field are needed.

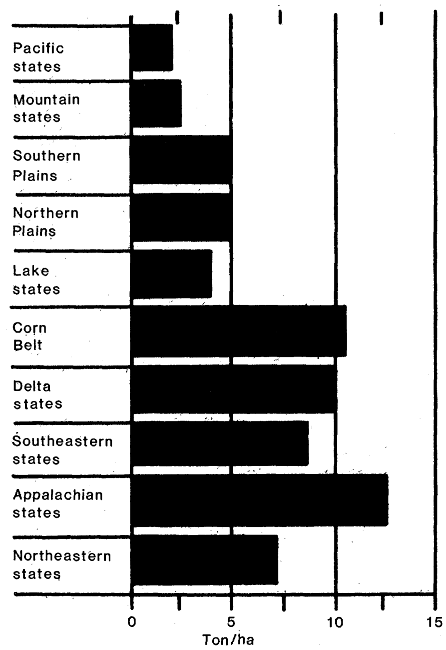


Fig. 3. Average sheet and rill erosion by cropland region in 1977 (7).

Measurement of Erosion

Quantifying energy flow at the soil surface temporally and spatially is extremely difficult. Most attempts to quantify erosion have involved the direct measurement of runoff and soil loss and the empirical relation of these measurements to soil, landscape, and climate.

Two methods for estimating soil erosion have predominated: the Universal Soil Loss Equation (USLE) (*17*) and the Wind Erosion Equation (WEQ) (*18*). The 1977 National Resource Inventory (NRI) data base (*8*) on erosion in the United States was derived from the application of these equations to data on soil, topography, climate, and soil management at specific sample sites.

Both equations were empirically derived. The USLE is statistically based on years of field plot measurements at 49 locations under natural rainfall conditions and additional measurements under simulated rainfall conditions. It calculates soil loss as a product of six factors:

$$A = R\,K\,L\,S\,C\,P$$

where A is estimated soil loss in metric tons per hectare per year, R is rainfall (a function of local rainstorm characteristics), K is soil erodibility (a function of soil properties), L is slope length, S is degree of slope, C is cropping (a function of crop type, residue management, tillage practices, and crop calendar), and P is erosion control (practices such as contouring, strip-cropping, or terracing).

The WEQ is based on soil erosion measurements by sediment traps at or near the soil surface and by wind tunnels in the laboratory or field. Wind erosion is calculated as a function of five factors:

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

where E is the potential annual soil loss, I is the soil erodibility (analogous to K in the USLE), K is ridge roughness (surface roughness and configuration), C is climate (wind speed and duration), L is the field length (unsheltered distance across a field parallel to the prevailing wind direction), and V is vegetative cover.

Both equations were designed to predict long-term (10 years or more) soil loss from fields under specific types of crop and soil management. Although erosion estimates obtained with these equations are, in fact, point measurements (*19*) and thus are not exact, they do indicate where potential erosion problems are likely to exist. The USLE, however, probably underestimates erosion in areas where rill and gully erosion are important and does not estimate sediment delivery to a stream.

Erosion is extremely variable with time. Most of the erosion of susceptible soils takes place during short intervals of high energy availability and when the soil is not protected by a mulch or crop canopy. For example, Browning *et al.* (*20*) reported that, annually, 13 percent of the storms causing runoff account for 60 percent of the erosion in southwest Iowa. Over 50 percent of the erosion from land planted in corn occurs in May

Table 1. Erosion data for five Minnesota watersheds (*16, 17*). [Adapted from (*15*)]

Watershed	Field erosion (ton/ha-year)	Drainage area (thousands of hectares)	Percentage of eroded material entering stream channels	Topographic description	Dominant soil taxonomic suborder (*36*)
Root River	7	329	26.9	Unglaciated or lightly glaciated uplands, 3- to 6-m local relief on crests, 9- to 18-m on ridge flanks	Udalfs
Zumbro River	12	293	3.3	Loess-mantled bedrock or ground moraine over bedrock, 3- to 6-m local relief on crests, 9- to 18-m on ridge flanks	Udalfs
Straight River	7	114	12.2	Terminal and ground moraine, irregular, 5- to 10-m local relief	Udalfs
Redwood River	4	181	0.6	Terminal or ground moraine, 2- to 15-m local relief	Borolls
Pelican River	2	125	0.8	Terminal or ground moraine, 2- to 15-m local relief	Borolls, Boralfs

and June. In the Great Plains, winds whose speeds are above threshold velocities for visibility reduction blow for a total of 400 to 2000 hours annually (*21*). Projecting long-term erosion, then, has the liability that assumptions must be made about climate and cropping practices.

Universality of Erosion

In 1977 the Soil Conservation Service completed the NRI (*8*), the most extensive quantitative study yet performed on the occurrence and amount of soil erosion in the United States. About 200,000 primary sampling units were randomly selected. Crop, soil, and topographic features were measured or observed at each unit. The data, along with geographic and other information, were used to estimate water (sheet and rill) erosion and wind erosion by the USLE and WEQ. These data form the basis of the RCA analysis (*6*) of soil erosion.

The seriousness of erosion must be viewed temporally in the context of maintaining crop production. The USDA has assigned a soil loss tolerance (*T*) value to most of the soils mapped in the United States. The *T* value, as defined by Wischmeier and Smith (*17*), "denotes the maximum level of soil erosion that will permit a high level of crop productivity to be maintained economically and indefinitely." *T* values never exceed 11.2 tons per hectare annually. Some are lower, depending on soil quality. (If a metric ton of soil represents about 0.0077 centimeter of soil over an area of 1 ha, a soil eroding at the rate of 13 ton/ha per year will lose about 1 centimeter of soil in 10 years.) *T* values are used in the RCA (*6*) to measure the extent and seriousness of erosion.

Average rates of sheet and rill erosion are shown in Fig. 3 for the major U.S. cropland regions. In 1977 erosion exceeded *T* on more than 45.4 million hectares of cropland (27 percent of the total) (Fig. 4). Approximately 10 percent of the cropland had erosion rates exceeding 22.4 ton/ha per year—twice the maximum soil loss tolerance (Table 2). These estimates do not include wind or gully erosion.

Other factors being constant, sheet erosion and rill erosion increase with steepness of the slope (*17*). Nationally, 45 percent of the cropland has slopes of 0 to 2 percent, 25 percent has slopes of 2 to 6 percent, 20 percent has slopes of 6 to 12 percent, and 10 percent has slopes over 12 percent.

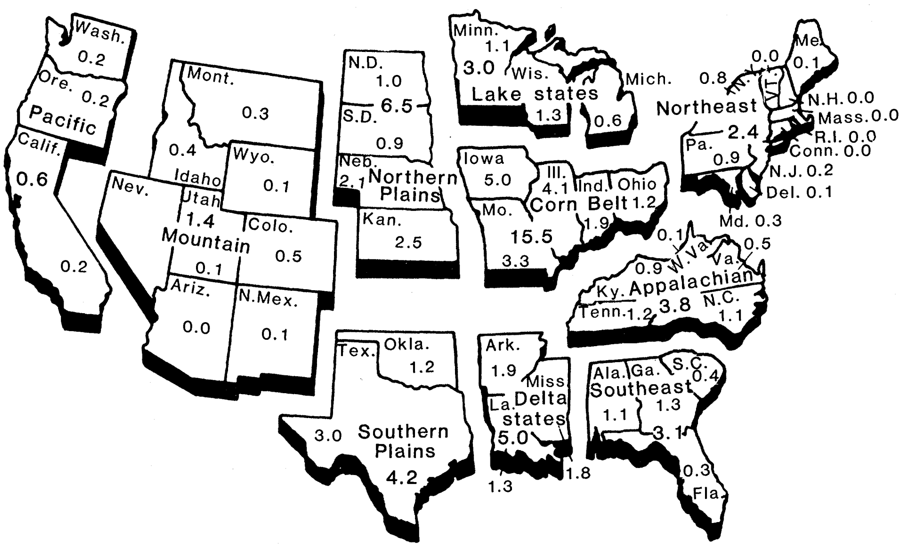


Fig. 4. Hectares of cropland (millions), by farm production region, on which the rate of sheet and rill erosion exceeded the soil loss tolerance level in 1977. [Adapted from (*6*)]

A factor contributing to increased erosion is the trend toward more production of row crops, chiefly corn and soybeans. Nationally, the area planted in row crops increased 27 percent between 1967 and 1977, close-grown crops increased 4 percent, and rotation hay and pasture decreased 40 percent. About 20 percent of U.S. cropland is now planted in corn and 16 percent is in soybeans. Over 80 percent of the cropland in the central Corn Belt is planted in corn and soybeans (Fig. 5). The cultivation of these crops on steeper slopes has increased significantly in recent years. Approximately 50 percent of the land in central Iowa and Illinois with slopes of 6 to 12 percent is planted in these two crops (*22*).

In 1977 average erosion rates exceeded *T* for all row crops produced in the Southeast (*8*). Annual soil loss exceeded

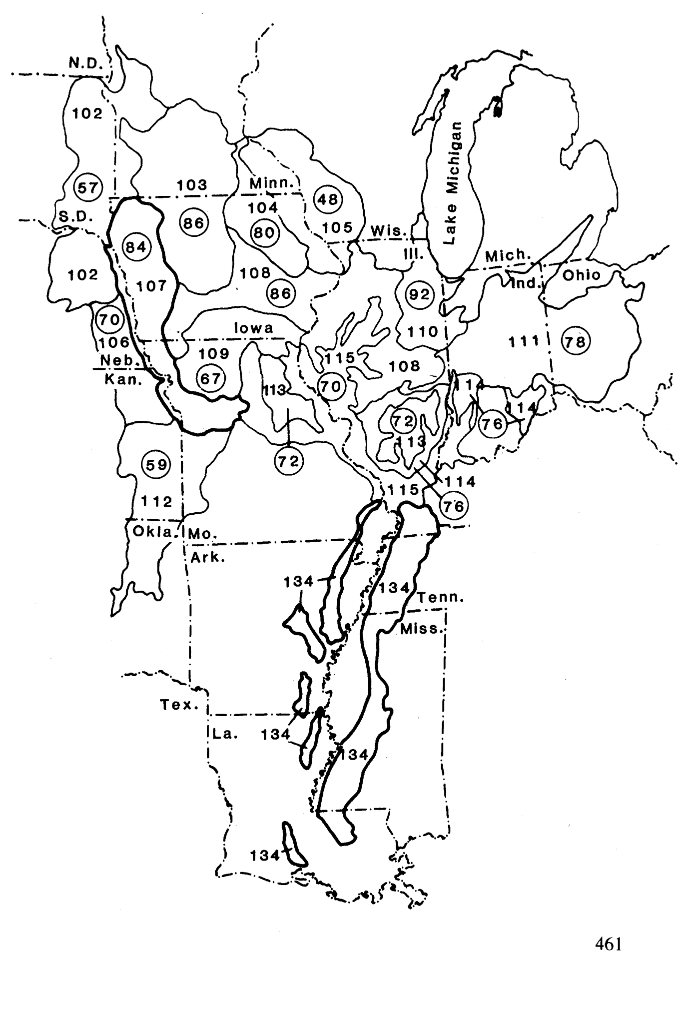


Fig. 5. Percentage of cropland planted in corn and soybeans in central grain and livestock regions (*22*). Percentages are circled. MLRA's 107 and 134 are shown in bold outline.

Table 2. Estimated amounts of sheet and rill erosion on U.S. cropland in 1977 (*6*).

Amount eroded (ton/ha-year)	Percentage of total cropland affected
< 4.5	48
4.5 to 11.2	28
11.2 to 22.4	14
> 22.4	10

22.4 ton/ha on 32, 19, and 9 percent of the cultivated areas in the Southeast, Northeast, and Corn Belt, respectively. Erosion rates were greater than *T* on 33 percent of the land planted in corn, 44 percent of the soybean land, 34 percent of the cotton land, and 39 percent of the sorghum land (Table 3). In general, erosion is greatest on land with row crops, less with close-seeded crops, and least with grass and legume forage crops.

Wind erosion is a serious problem in many areas of the nation, especially the Great Plains. Wind erosion may be expected to occur "whenever the surface soil is finely divided, loose, and dry; the surface is smooth and bare; and the field is unsheltered, wide, and improperly oriented with respect to the prevailing wind direction" (*23*). Except for a ten-state area of the Great Plains, the extent of wind erosion was not quantified in the RCA because of insufficient data for the WEQ (*6*). Cropland in Texas, New Mexico, and Colorado has average wind erosion rates exceeding 11.2 ton/ha per year (Fig. 6).

Impact of Erosion on Productivity

Plant growth depends on a favorable combination of light, mechanical support, heat, air, water, and nutrients (*11*). The principle of limiting factors indicates that the least optimal factor will determine the level of crop production. The soil and landscape supply most of the factors essential to plant growth. These factors have been optimized through manipulation, so that over the past few decades the United States has experienced a linear increase in crop production. Erosion, however, may raise the costs of optimization until they are prohibitive, making it impossible to sustain production levels.

We have been very successful at optimizing the nutrient status of soils, and are learning to optimize the physical character of the surface soil. Irrigation has raised production levels significantly in many drier areas. The cost-benefit ratio of this technology has been favorable but—with unstable energy costs, a reduction in fertilizer reserves, and depletion of aquifers—the ratio is becoming less favorable. Most technological advances in soil manipulation have been in the management of the A horizon. Optimizing conditions in the subsoil is costly, difficult, or impossible.

The long-term effects of soil erosion on crop production might be estimated by examining soil profile characteristics in terms of irreplaceable inputs (*24*). Pierce *et al.* (*25*) presented an approach for quantifying the long-term effects of erosion on productivity. The approach is based on a model developed by Kiniry *et al.* (*26*) and on data compiled by the Soil Conservation Service (*8, 27*). Using parameters of available water capacity, bulk density, *p*H, and permeability and weighting them in accordance with an idealized root distribution, Pierce *et al.* (*25*) calculated the change in the soil productivity index (PI) after 25, 50, and 100 years of simulated erosion as reported in the NRI (*8*). PI can vary from 0.0 to 1.0, with 1.0 representing the highest level of productivity.

In the approach used by Pierce *et al.* (*25*), the soil is viewed as an environment for root growth and water depletion. It is assumed that soils with favorable characteristics throughout a deep profile exhibit little change in long-term productive potential due to erosion, but that soils with unfavorable characteristics in the subsoil or the parent material undergo serious reductions in productivity with time. It is also assumed that high-technology management is applied, that is, that such things as fertilizers and cultural management practices are not limiting and that climate is similar in a given area.

Table 3. Proportion of lands, planted in various major crops, experiencing stated rates of sheet and rill erosion (*6*). Values are percentages.

Crop	Erosion rate (ton/ha-year) < 11.2	11.2 to 22.4	> 22.4
Corn	67	17	16
Soybeans	56	26	18
Cotton	66	22	12
Sorghum	61	23	16
Wheat	87	9	4
Peanuts	53	32	15
Tobacco	47	26	27

While this approach is a first approximation, it holds promise as a tool to quantify the long-term effects of erosion on soil productivity (*28*). We applied the method to two MLRA's identified by the RCA as critical erosion areas (Fig. 5) (*29*). Necessary data were obtained from the SOILS 5 (*27*) official series description data base and the NRI. It was assumed that erosion would continue at the 1977 rate. The results are summarized in Table 4. Several features of the data are extremely important for understanding the effects of erosion on soil productivity. Both MLRA's have similar but high average erosion rates (31 and 38 ton/ha per year). Likewise, the rate of erosion increases sharply with increased slope in both MLRA's. However, the computed loss in productivity with continued erosion is minimal in MLRA 107 but severe on steeper slopes in MLRA 134. This difference is readily explained by differences in soils (*13*).

Most soils in MLRA 107 were developed from deep loess material of rather uniform loam to silty clay loam and are physically similar to a depth of 3 to 12 meters. In these soils the conditions for root growth and water storage do not vary much with depth. Although the soils are eroding at extremely high rates, particularly on the steeper slopes, the irreplaceable attributes (*24*) of a majority of the soils are not being materially damaged. The lower initial PI's for the less sloping areas (0.84 for 0 to 2 percent

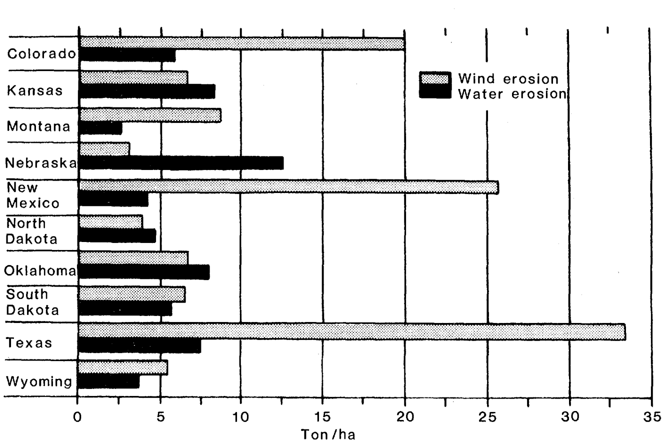


Fig. 6. Average annual wind and water erosion for the Great Plains states (*6*).

slopes, 0.94 for 2 to 6 percent slopes) reflect the occurrence of a considerable area of soils with clayey surface horizons in the Missouri River floodplain.

The soils in MLRA 134 are developed from a loess mantle overlying unconsolidated sands, silts, and clays, mainly of marine origin. As in many areas, the thickness of loess varies between the ridge divides and gentle slopes. Another feature of MLRA 134 is the common occurrence of fragipans, subsurface horizons with high bulk density. Seemingly cemented when dry, fragipans cannot be penetrated by roots. As erosion continues over the next 50 to 100 years, bringing the fragipans nearer to the surface, the PI will drop markedly. Thus, the marked drop in PI on slopes of over 6 percent reflects an initially thinner favorable soil material and greater erosion rates, compared to slopes of less than 6 percent. Under current economic conditions, many soils on slopes of over 6 percent will probably go out of row crop production because of poor yields. The percentage of cropland in slopes of over 6 percent is 38 percent in MLRA 107 and 10 percent in MLRA 134.

The analysis illustrates that soil erosion rates alone are not necessarily good indicators of damage to productivity. The results in Table 4 are based only on losses of irreplaceable soil attributes to erosion. Nutrient losses, losses from gullying, direct damage to plants, and off-site damages are not considered.

The productivity loss estimates discussed above are conservative, since the cost of technological inputs may also prove limiting to crop production. Additional consequences of erosion must be considered as well. Off-site erosion damage is often the most spectacular and costly in the short term (*30*), and it contributes to water pollution. (However, it is difficult to distinguish between naturally occurring sediment and sediment resulting from man-made erosion.) Erosion damage to crops occurs as a result of the abrasive action of wind on plants, removal of plants by water laden with eroded soil, and deposition of soil on plants, especially young seedlings. Crop damage may occur when erosion rates are below those considered damaging to soil (*31*). Loss of plant nutrients is a major consequence of erosion, resulting in both on-site and off-site damage. On a national scale, losses of nitrogen, phosphorus, and potassium approach $677 million, $17 million, and $382 million per year, respectively (Table 5) (*32*). Consideration of the costs of long-term availability of these nutrients would increase cost estimates.

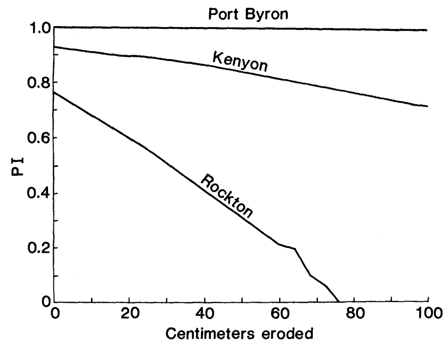


Fig. 7. Productivity index (*PI*) plotted against centimeters of soil removed (*25*). The average slopes for the Port Byron, Kenyon, and Rockton soils are 0, −0.002, and −0.008, respectively, and they reflect the vulnerability of the soils to the loss of nonreplaceable attributes.

The postulated relation between erosion and soil productivity should be verified further as more data are obtained. These relations can then be used in making soil conservation policy. For example, from what we have learned, conservation efforts should be concentrated where erosion damage is greatest, not necessarily where the greatest amount of erosion occurs.

Soil Vulnerability

At the heart of the erosion issue is the question of soil loss tolerance with respect to crop production. The concept of the *T* value is vague, and, according to Wischmeier and Smith (*33*), "establishment of tolerance values has been largely a matter of judgment based on observations." Many believe that *T* values represent the rate of soil formation from consolidated materials. However, the rate of soil formation from unconsolidated materials is less than 1 ton/ha per year, and soil formation from consolidated material proceeds at an even lower rate (*34*).

An alternative approach to *T* values is the concept of vulnerability curves (*25*). Vulnerability curves show PI plotted against soil removal (Fig. 7). The average slope of a curve represents the relative vulnerability (*V*) of a particular soil to long-term erosion losses. These curves are independent of erosion rates and reflect the productivity of soils. The distributions of *V* for soils in MLRA's 107 and 134 (Fig. 8) show that 14 and 32 percent of the cropland area, respective-

Table 4. Soil erosion rates, initial productivity, and changes in productivity after 50 and 100 years of erosion in two MLRA's broken down by slope class.

MLRA	Slope (%)	Hectares (thousands)	Soil loss (ton/ha-year)	Initial PI	Loss in PI (%) 50 years	Loss in PI (%) 100 years
107	0 to 2	852	5	0.84	< 1	< 1
	2 to 6	1156	18	0.94	1	2
	6 to 12	819	61	0.94	3	5
	12 to 20	376	114	0.96	3	4
Overall		3203	38	0.91	2	3
134	0 to 2	1841	12	0.78	1	2
	2 to 6	659	36	0.76	4	8
	6 to 12	234	113	0.72	16	23
	12 to 20	46	213	0.76	15	15
Overall		2780	31	0.77	3	5

Table 5. Total and available nitrogen, phosphorus, and potassium in eroded sediments (*32*). Values are thousands of metric tons.

Region	Nitrogen		Phosphorus		Potassium	
	Total	Available	Total	Available	Total	Available
Pacific	100	18	29	0.6	1,154	23
Mountain	176	32	64	1.3	2,550	51
Southern Plains	512	94	101	2.0	3,043	61
Northern Plains	2,068	380	293	5.9	11,711	234
Lake states	622	114	107	2.1	3,643	73
Corn Belt	4,360	802	624	12.5	24,959	499
Delta states	478	88	141	2.8	4,220	84
Southeastern states	202	37	101	2.0	1,007	20
Appalachian states	676	124	169	3.4	3,381	67
Northeastern states	300	55	75	1.5	2,252	45
Total	9,494	1,744	1,704	34.1	57,920	1,158

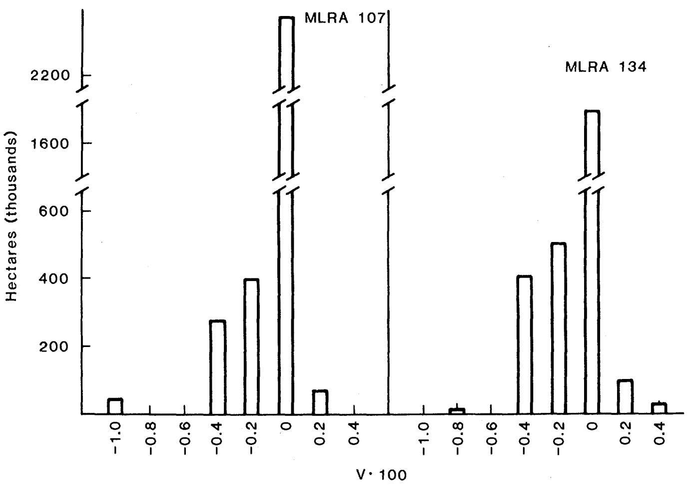


Fig. 8. Distribution of soils in MLRA's 107 and 134 by vulnerability ($V \cdot 100$) to erosion.

ly, are highly vulnerable ($V < -0.002$) to losses in productivity from erosion (that is, the decrease in PI exceeds 0.002 with a 1-cm soil loss). On these soils removal of 1 cm of the surface would result in a productivity decrease of 0.2 percent or more. Of the cultivated areas in MLRA's 107 and 134, 6 and 26 percent, respectively, have $V < -0.002$ and an erosion rate > 11.2 ton/ha per year. Only 1 and 4 percent of the cropland areas have $V < -0.002$ and slopes > 6 percent (Fig. 8). These data indicate that a small but significant percentage of the soils has the potential for serious reductions in productivity due to erosion.

For most of MLRA 107, long-term productivity is not particularly vulnerable to soil erosion because of the deep character of the soils and the general lack of unfavorable subsurface horizons. The few soils whose PI would be improved by erosion are largely alluvial, with high clay contents in the surface horizons.

MLRA 134 has a considerable area with $V < -0.002$. Most of these soils have fragipans. As in MLRA 107, soils with positive V values are primarily alluvial.

Stresses on the Resource Base

The potential impact of erosion on agricultural productivity must be assessed in terms of both the total cropland available and the future needs of the nation. In 1977 the United States had 168 million hectares in crop production and an additional 51 million hectares with high or medium potential for conversion to cropland, for a total base of 219 million hectares (*6*). The base is subject to noncrop use, damage from erosion and other forms of degradation, and the effects of increases in production per unit of land area. According to a recent USDA study (*7*), it is likely that the entire U.S. cropland base will be in production by the year 2000. Although it is not our objective to discuss the adequacy of available cropland resources, it is pertinent to comment on the possible effects of erosion on the cropland base.

The results given in Table 4 suggest a minimum reduction of 5 to 10 percent in the productivity of cropland in MLRA's 107 and 134 during the next 100 years if erosion continues at the 1977 rate. If the loss in crop production from erosion on the current 168 million hectares of cropland is 0.1 percent per year, then the equivalent of 4.2, 8.4, and 16.8 million hectares of productive cropland will be lost over the next 25, 50, and 100 years, respectively. These losses loom even larger when the costs of replaceable inputs, poor management of land, and removal of erosion-damaged land from production are considered.

Of the 51 million hectares of potential U.S. cropland, more than half is susceptible to erosion (*35*). Selectivity in bringing this land into production and improved conservation practices will be needed to safeguard this reserve. Conservatively assuming that erosion-induced losses in crop production on the potential cropland will also be 0.1 percent, the equivalent loss will be 1.3, 2.6, and 5.1 million hectares over the next 25, 50, and 100 years, respectively. Adding the losses from land now under cultivation to those from potential cropland results in losses of 5.5, 11, and 22 million hectares over the period considered. While losses of this magnitude are not catastrophic, they would hasten the time when our total cropland base would be in full production.

While additional land with low potential for use as cropland (101 million hectares) could be converted to cropland, this would require substantial capital expenditures for clearing, draining, and land forming. High annual expenditures for erosion control, fertilization, and other inputs necessary to sustain production would follow. In addition, the environmental consequences of bringing such land into cultivation would be enormous. Development of technology and conservation systems to facilitate the economic use of this land is a major challenge for researchers.

Conclusions

The effects of erosion on cropland soils depend on the characteristics of the soils and the landscapes in which they occur. Further, when considered in the context of long-term productivity, erosion rates alone are not good indicators of soil degradation. Erosion rates should not be the sole criterion in targeting government resources for erosion control.

Degradation of irreplaceable soil attributes is much more serious on some soils than others when compared at the same erosion rates (compare Port Byron with Rockton in Fig. 7). If the slope of the line in Fig. 7 is used as an index of the vulnerability of soils to erosion, then the frequency distribution of seriously vulnerable soils can be seen to vary with the landscape. For example, the deep loess soils in MLRA 107 are, as a group, less vulnerable than the soils in MLRA 134 to losses of irreplaceable attributes. Degradation of soil resources is most serious on the steeper slopes because of higher erosion rates and—usually, but not always—less favorable subsoils.

We have concentrated on losses in irreplaceable soil attributes. The data presented here for two MLRA's indicate that a significant percentage of soils has the potential for serious losses in productivity due to erosion. This percentage would become very large if we became unable to apply the advanced technology needed to optimize factors affecting plant growth. When losses in replaceable and irreplaceable soil attributes, damage to plants, gullying, off-site damage from sediment, and contribution of particulates to the air are considered, the seriousness of the erosion threat becomes disturbingly clear. As a national problem, soil erosion deserves greater attention from scientists, the government, and the public.

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27. The SOILS 5 data base, compiled by the Soil Conservation Service, contains soil descriptions, physical and chemical properties, crop yields, and capabilities and limitations for every soil series and their variants established in the United States.
28. For soils in MLRA 103 in Minnesota, 71 percent of the variability in corn yield [(as reported in SOILS 5 (*27*)]) was accounted for by the regression of corn yield on the calculated PI (*25*).
29. Areas identified as having particularly high water erosion rates (*7*) are (i) Aroostook County, Maine; (ii) Palouse and Nez Perce prairies and the Columbia Plateau (eastern Washington, north-central Oregon, west-central Idaho); (iii) silty uplands of the southern Mississippi Valley (western parts of Tennessee, Kentucky, and Mississippi; an area northwest of the Mississippi River in Louisiana; and Crowley's Ridge in eastern Arkansas); and (iv) Loess, Till, and Sandy prairies (Nebraska, Kansas, South Dakota, southwestern Minnesota, western Iowa, and northwestern Missouri).
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