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Soil Erosion and Productivity[1]

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Soil is comprised of mineral and organic materials that have weathered or decomposed over many years and in some cases a millennium to create the resource that most of us rely on for our livelihoods, and mankind for its survival. There are many phenomena that work together to weather rocks and minerals that include biological, chemical, and physical processes. Weathering, most greatly affected by climate, ages a soil over time. It has been estimated that it takes several centuries to create 1 inch of soil, and it became very apparent in 2000 that erosion could take away much of this resource in a few hours.

Soil erosion is a natural process where the forces of nature move vulnerable soil toward the sea. Very simply put wind and water provide the energy needed to detach soil particles and transport them until their energy decreases and the particles are deposited. Man's activities increase the potential for erosion because practices such as agriculture, as well as various types of construction leave the soil bare and vulnerable to the elements.

It is well known that raindrop impact provides the force that begins water erosion. Raindrops traveling about 20 mph can splash soil particles as far as 5 feet. The raindrop energy also compacts and seals the soil surface, with finer particles filling voids, thereby reducing infiltration and initiating runoff. Initially the runoff flows as a discontinuous sheet over the land. As the volume of runoff and sediment increases, its ability to scour and suspend particles increases. Under some runoff conditions small channels, or rills, are created with the amount of erosion dependent upon the length and steepness of the slope. Recognized as "sheet and rill erosion," this process is somewhat insidious because it is easily covered up by subsequent tillage. People often point out gully erosion because it is very obvious, but sheet and rill erosion has the potential to remove much more soil off the landscape.

Wind erosion is a less obvious form of erosion unless one happens to be on a sand plain or areas of silt deposit on a windy day in the spring or fall when the soil is not protected by vegetation. The process of wind erosion involves detachment of soil, usually by other wind-blown soil particles.

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This phenomenon is known as saltation. Finer particles can be suspended in the atmosphere by wind and moved some distance until a barrier, such as a tree line, slows the wind velocity. Larger particles that are not suspended may creep along the surface. Sandy and silty soils are more susceptible to wind erosion because the individual soil particles are not tightly held together by aggregation. Wind erosion is responsible for the "snirt" found in fencerows in the winter.

Currently there is considerable interest in the relationship between erosion and surface water quality. This is without argument a very important issue. Nutrients and sediment in lakes and streams degrade water quality and change the biology of these water features. What is perhaps more poorly appreciated is the effect that erosion has on the productivity of the soil back in the fields. A portion of the topsoil is the product of erosion. Erosion takes away a disproportionately more pro-ductive amount of the soil profile that contains nutrients, organic matter, and microorganisms.

We are currently "blessed" with a surplus agricultural productive capacity in the US. While it is not the intent of this paper to forecast doom and gloom for mankind, it should be recognized that the soil is a finite resource and its management must be improved. It has been estimated that nearly one-third of the world's arable land has been lost to erosion in the last 40 years and continues to be lost at a rate of 25 million acres per year (Pimental et al., 1995). Most of this loss is in developing countries, where population pressures result in non-sustainable land management practices. Erosion rates are highest in Asia, Africa, and South America, averaging 13 to 18 tons/acre/year. Pimental et al. (1995) suggest that, although erosion rates in the US are considerable lower, approximately 30% of the farmland has been abandoned because of erosion, salinization, and water-logging. They state that 90% of US crop land is losing soil at a rate greater than it is replaced (~ 1 ton/year).

The productivity loss associated with erosion is obvious to anyone who has viewed the sloping fields that are so common on Wisconsin's rolling, glaciated landscape. Areas of shallow soil often run short of water and senesce early in the season, with little yield. If one thinks about the long-term consequences of erosion, only a 180-degree turn in management will improve soil productivity.

What is an eroded soil and is there a group of measurable soil properties that will quantify erosion its affects? Lowery et al. (1995) evaluated soil physical data collected from "benchmark" soils in 11 North Central states. Erosion was classified as slight (<25% initial A horizon lost), moderate (25 to 75% A horizon lost), and severe (>75% A horizon lost). Most of the changes noted were found in the Ap horizon and would be expected to have a direct impact on crop growth. As erosion severity increased, the bulk density and clay content increased and available water and saturated hydraulic conductivity decreased.

Crop yields are lower on eroded soils because of a complex of factors that affect soil quality. Soil quality is difficult to define, but it can be considered as the interaction of a soil's physical, chemical, and biological properties that support crop growth. As previously mentioned, eroded soil contains the "best" part of the soil profile considering that nutrients and organic matter are concentrated in the soil's upper layers. The upper layer of a severely eroded soil becomes what was the subsoil, and generally develops poorer tilth. Lal et al. (1999) suggest that there is a strong corre-lation between soil quality and erosion; i.e., soil quality affects the rate of erosion and the quality of a soil is affected by the erosion. They describe the major soil quality effects of erosion that impact productive capacity as follows: 1) a decrease in rooting depth; 2) reduction in available water;

3) loss of soil organic matter; 4) loss of structure; 5) soil fertility problems; and 6) loss of soil biodiversity.

It may be impossible to cite one of these factors as most important, but arguably the availability of water to crops should be at the top of a list. Eroded soils have inferior water relationships because erosion that typically result in decreased infiltration, water storage, plant water availability, and increased runoff. Crops require a tremendous amount of water. A modest-yielding corn crop has been estimated to need over 400,000 gal water/acre or about 16 acre-inch.

Andraski and Lowery (1992) examined the impact of erosion on soil water relationships and its effect on corn production on a southwest facing Dubuque silt loam at the Lancaster Agricultural Research Station (Table 1). Erosion class was identified as the depth to red clay subsoil (36 inches = slight; 30 inches = moderate; 18 inches = severe). Their study found decreasing available water in the top 3 feet of the soil as the severity of erosion increased. Evapotranspiration rate at silking (when water is critical) was lower on the eroded sites as were the maximum heights obtained by the corn. Grain yield was also lower on the eroded areas. Although these differences are not dramatic, they did result in about a 10% loss in productivity.

Table 1. Relationship between erosion class, available water, ET rate, and corn height growth and yield at Lancaster, WI (after Andraski and Lowery, 1992). †

Erosion class	Available water	Silking ET rate	Height maximum	Grain yield
	inches/3 ft	inch/day	inches	bu/acre
Slight	7.8	0.17	91	146
Moderate	7.4	0.15	86	136
Severe	6.9	0.14	81	137

† Average of 1985-1988.

If a site is severely eroded, is there anything that a producer can do to "reclaim" the lost productivity? Researchers in western Canada (Larney et al., 2000) conducted an interesting study where they removed 0, 2, 4, 6, and 8 inches of topsoil to simulate erosion. They then superimposed treatments of nothing, 70 lb N + 20 lb P_20_5/acre as fertilizer, 2 inches of topsoil re-applied, and 30 ton/acre of manure over the removal area. Removal of 8 inches of soil reduced yield by nearly 50%. Fertilization was the least effective method of reclaiming productivity, whereas manuring was the most effective (Table 2). The addition of micronutrients in the manure was speculated to be a partial reason for the response.

Arriaga (2000) examined the use of cattle manure as an ameliorating amendment for an eroded site at the Lancaster Agricultural Research Station over a period of 12 years. Previous study at this location showed that productivity was closely related to available water (Andraski and Lowery, 1992). It is hypothesized that manuring will improve the water availability characteristics of a soil.

Table 2. Influence of various amendments on the amelioration of lost productivity (wheat yield) associated with simulated erosion on a non-irrigated and irrigated site (after Larney et al., 2000).

Soil removed	Check	Fertilizer	Manure	Topsoil
inches	---------------------------------- bu/acre -----------------------------------			
		Non-irrigated		
0	18	24	18	22
2	16	22	27	19
4	7	16	25	18
6	4	7	27	13
8	3	6	25	13
		Irrigated		
0	37	40	40	37
2	27	34	34	34
4	13	30	31	30
6	7	16	33	22
8	4	10	31	16

This site was been split into manure treated and non-treated areas in 1988. Liquid manure was injected in the first 4 years and solid manure was fall applied and chiseled after 1992. The manure application rate varied between years and the nitrogen fertilizer rate was applied at the recommended and half the recommended rate in the non-manured and manured treatments, respectively.

Arriaga (2000) found greater productivity (grain yield) in the manure treatments in 9 of 12 years. The average difference over all years was about 8 bu/acre. The greatest differences were found in the slightly eroded treatments, suggesting that manuring alone will not restore productivity on severely eroded sites. The effect of manure treatment on selected soil physical properties on soils having varying erosion is shown in Table 3. Manure treatment was found to increase soil organic C, which would be expected to have a relationship soil aggregation. Soil bulk density was lower in the plow layer on each of the slightly, moderately, and severely eroded plots. Hydraulic conductivity in saturated soil cores tended to be higher in the eroded plots, with this difference more pronounced in the moderately and severely eroded treatments.

So far this paper has addressed the ability of water and wind to move soil. Another potential process by which soil can be moved is through tillage erosion or more properly—tillage transloca-tion. Research in this area is receiving considerable interest, especially because of site-specific technology, which provides the capability to spatially view its effects. Simply explained, tillage translocation is the movement of soil off convex or sloping areas to concave or level areas within a field. The resulting soil movement may have minimal environmental or water quality implications because the soil is typically not transported away from the field. There may be a substantial effect on the productivity of both the eroded and depositional areas.

Table 3. Effect of 10 years of manuring a soil with varying levels of erosion on selected soil physical properties at Lancaster, WI (after Arriaga, 2000).

Erosion class	Manure	Organic C at 6 inches	Bulk density (0 to 6 inches)	Hydraulic conductivity
		%	g/cc	cm/sec
Slight	No	1.4	1.32	0.0003
	Yes	2.1	1.15	0.0007
Moderate	No	1.6	1.32	0.0010
	Yes	2.4	1.21	0.0019
Severe	No	1.8	1.30	0.0009
	Yes	2.5	1.20	0.0025

It is not difficult to visualize tillage translocation. When an implement is tilling downslope vs. upslope, it is expected that there will be a net movement of soil in the downslope direction. The steeper the slope, the greater the net downslope movement. Tillage translocation is likely a major reason for the creation of eroded knolls that dot our glacial landscape. These locations were also areas of lower deposition of loess. The final net effect of tillage translocation is the leveling of the landscape.

During the initial phases of tillage translocation, topsoil from the upland fills the depressional areas. However, with continued soil movement, subsoil from the upland covers topsoil in the depressions, resulting in an “inverted profile” where the subsoil is on top of the topsoil. An example of this was observed in a grid-sampled field near Waunakee, Wis. where calcareous till was moved into depressions surrounding eroded knolls, resulting in relatively high pH levels.

Combined with the effects of water erosion, tillage translocation is likely to produce some long-term differences in productivity within fields. Schumacher et al. (1999) compared tillage transloca-tion and water erosion for a catena with a maximum 8% slope. Their model showed that tillage translocation would have its greatest effect at slope breaks — the crest and foot of slopes. Water erosion was greatest along the face of the slope, increasing near the foot. Their model of productivity across an 80-m transect showed slight decreases in productivity at the summit of the slope, relatively large decreases at the slope break and on the main slope face, and a productivity increase at the foot slope (Table 4).

Table 4. Model of productivity index as affected by tillage translocation and the additive effect of water erosion across an 80-m transect of a South Dakota soil (after Schumacher et al, 1999).

	Soil productivity index							
	Summit		Shoulder		Backslope		Footslope	
Erosion process	10 m	20 m	30 m	40 m	50 m	60 m	70 m	80 m
Tillage translocation	0.87	0.72	0.67	0.70	0.86	0.86	0.92	0.91
Tillage translocation + water erosion	0.87	0.70	0.64	0.64	0.80	0.81	0.95	0.95

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