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Review Paper

Natural and anthropogenic rates of soil erosion

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ABSTRACT

Regions of land that are brought into crop production from native vegetation typically undergo a period of soil erosion instability, and long term erosion rates are greater than for natural lands as long as the land continues being used for crop production. Average rates of soil erosion under natural, non-cropped conditions have been documented to be less than 2 Mg ha^{-1} yr^{-1}. On-site rates of erosion of lands under cultivation over large cropland areas, such as in the United States, have been documented to be on the order of 6 Mg ha^{-1} yr^{-1} or more. In northeastern China, lands that were brought into production during the last century are thought to have average rates of erosion over this large area of as much as 15 Mg ha^{-1} yr^{-1} or more. Broadly applied soil conservation practices, and in particular conservation tillage and no-till cropping, have been found to be effective in reducing rates of erosion, as was seen in the United States when the average rates of erosion on cropped lands decreased from on the order of 9 Mg ha^{-1} yr^{-1} to 6 or 7 Mg ha^{-1} yr^{-1} between 1982 and 2002, coincident with the widespread adoption of new conservation tillage and residue management practices. Taking cropped lands out of production and restoring them to perennial plant cover, as was done in areas of the United States under the Conservation Reserve Program, is thought to reduce average erosion rates to approximately 1 Mg ha^{-1} yr^{-1} or less on those lands.

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1. Introduction

It is difficult to imagine an aspect of our natural world which encompasses such an immense measure of scale in both time and space as erosion of the earth's surface. A student of erosion will find that one must think in terms of microseconds in order to understand the mechanics of impact of a single raindrop on a soil surface. In one erosion study, the impact pressures of raindrops on a soil surface were recorded at a rate of one data-point per 500 ns in order to capture those few microseconds of peak impact pressures (Nearing, Bradford, & Holtz, 1987). Toward the other end of the erosional time scale, the Quaternary landscapes of Iowa which formed over the last 10,000 to 12,000 years (Ruhe, 1969) may be considered relatively young, and the forces which carved the erosional surfaces of the Appalachian mountain range acted over millions of years (Thornbury, 1965). Erosion scientists study in spatial scales which span from millimeters for raindrops to

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Table 1
Selected data from the scientific literature on geologic rates of soil erosion.

Research study	Measurement method	Location	Material	Spatial scale	Geologic time range (years BP)	Erosion rate (Mg ha^{-1} yr^{-1})
Granger et al. (1996)	^{10}Be conc. of Sediments	Northeast California	Granodiorite Fault Block	13.2–40.8 ha	16,000 to present	0.95–1.6
Granger et al. (1996)	Sediment Accumulation and ^{14}C	Northeast California	Granodiorite Fault Block	13.2–40.8 ha	16,000 to present	0.8–1.5
McKean et al. (1993)	^{10}Be conc. of Soil Profile	Central California	Weathered Marine Shale	~50 m	3500 to present	0.24–0.41
Ruhe and Daniels (1965)	Sediment Accumulation and ^{14}C	Adair County, Iowa, U.S.A.	Loess and Glacial Till	1.8 ha	6800 to 125	1.9[a]
Walker (1966)	Sediment Accumulation and ^{14}C	Central Iowa, U.S.A.	Glacial Till	~28 ha	12–14,000 to present	0.8–1.8
Norton (1986)	Soil Profile Depths and ^{14}C	East central Ohio, U.S.A.	Loess	1.56 ha	17–28,000 to present	0.035–0.06

[a] Assumes a soil bulk density of 1.25 Mg/m^3.

megameters for continents. The erosion topic covers a lot of ground.

In addition to spanning broad scales of time and space, erosion also has enormous implications for our everyday world, although we often take them for granted. Perhaps the most basic of implications is, as Ruhe (1969) wrote, that “most landforms are products of erosion”. Not all are, but most are. Thus, we live on a landscape that is the product largely of erosion. A second implication of erosion is that it creates sediment, which is a pollutant. In fact, by shear volume or mass, sediment is by far the greatest pollutant we have. The associated economic costs of sediment as a pollutant are debated, but undeniably sediment effects tremendous societal cost in terms of stream degradation, disturbance to wildlife habitat, flooding, and direct costs for dredging, levees, and reservoir storage losses (Ribaudo et al., 1989; Clark, 1985; Pimentel, 2006). Sediment is also an important vehicle for the transport of soil bound chemical contaminants from non-point source areas to waterways. According to the USDA-Soil Conservation Service (1989), soil erosion is the source of 80% of the total phosphorus and 73% of the total nitrogen in the waterways of the U.S. Sediment also carries agricultural pesticides and other land applied chemicals. Solutions to non-point source pollution problems invariably must address the problem of erosion and sediment control.

The most important, and insidious, implication of accelerated erosion, however, is the role it plays in soil degradation. Soil degradation is by its nature a gradual process, and the effects are not always evident until after the damage is done. Soil degradation is thought to have been a major contributor to the decline of civilizations (Lowdermilk, 1953), and soil erosion is currently the major contributor to the degradation of the global soil resource (Bridges & Oldeman, 1999). Current rates of soil degradation continue to be greater than rates of soil formation, and soil degradation threatens basic food production capabilities in certain parts of the world, even in the short term (Scherr, 1999).

Increases in human population have caused many areas of the world to undergo rapid changes from an essentially natural environment to one dominated by intensive agricultural. In this paper we will discuss the transition from natural lands to intensive agricultural production lands. A short overview of natural, geologic rates of erosion is given, followed by the discussion of erosion trends in the transition to intensive agriculture. Examples are given for experiences in the United States and Northeastern China.

2. Recent geologic rates of erosion

In order to understand modern rates of erosion in perspective, it is useful to have some understanding of geologic, or “natural”, rates of erosion. The evidence is clear that human activities substantially and often dominantly impact erosion rates, at least within certain temporal and spatial scales. In general, one would expect that geologic rates of erosion would be roughly equivalent to rates of erosion that we observe today in natural settings that have not had significant anthropogenic influence. There are two problems with relying on this logic, however. One is related to time, and the other to place. It is possible that geologic erosion rates may be greatly influenced by infrequent catastrophic erosion events that occur over a short time period, and which would often not be observed over the short time scales of observation we are usually able to make in natural areas today. The other issue is that the natural areas today do not represent a random selection of the natural world as it was prior to human influence, and in particular to agriculture. Humans have not randomly settled the earth. We have chosen those areas that suit specific needs for food production and living. The loess belts of the world, for example, are major grain producing regions. Loessial soils are highly erodible, and finding significant areas of uncultivated natural areas in loess deposits in humid areas would be difficult.

Geologic rates of erosion have been quantified using primarily stratigraphic information associated with sediment deposits. In the studies of Ruhe and Daniels (1965) and Walker (1966), sediment deposits were measured in a depositional area below a known source area. Both studies were conducted in Iowa, USA in an area that was glaciated until approximately 11,000 to 14,000 year BP (before present). The sediments in both cases were dated using radiocarbon techniques. Rates of erosion estimated for those studies were within the range of 0.8–1.9 Mg ha^{-1} yr^{-1} (Table 1). In a very different environment, Granger, Kirchner, and Finkel (1996) surveyed the accumulated volume of two fan deposits in the Fort Sage Mountains of northeastern California, and measurements of ^{14}C in lake carbonates dated the base of the alluvial fans at $16{,}100 \pm 400$ years. Hillslope gradients in the sub-catchments were reported as ranging from 23% to 63%. The sediment volume data produced an estimate for the average erosion rate of 0.95–1.6 Mg ha^{-1} yr^{-1}.

Studies on recent geologic erosion rates have also been made using ^{10}Be techniques. ^{10}Be is a cosmogenic nuclide that is produced by the bombardment of cosmic radiation on atomic nuclei in minerals near the earth's surface (Lal & Peters, 1967). Erosion rates or changes in rates have been inferred both from measurements of ^{10}Be concentrations on outcropping surfaces (Nishizumi et al., 1993; Bierman, 1994) and from ^{10}Be in sediment deposits (Brown, Pavich, Hickman, Klein, & Middleton, 1988; Granger et al., 1996; Valette-Silver, Brown, Pavich, Klein, & Middleton, 1986). For both cases it can be shown (Granger et al., 1996) that the cosmogenic nuclide concentration, N, in either the outcropping surface