Long-term soil erodibility database, Walnut Gulch Experimental Watershed, Arizona, USA

F. E. Rhoton[1], W. E. Emmerich[2], D. C. Goodrich[2], S. N. Miller[3], and D. S. McChesney[1]
[1]National Sedimentation Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Oxford, MS, USA; [2]Southwest Watershed Research Center, Agricultural Research Service, Tucson, AZ, USA; [3]Department of Renewable Resources, University of Wyoming, Laramie, WY, USA.

Abstract. The Walnut Gulch Experimental Watershed in southeastern Arizona is characterized by a wide variety of geologic parent materials, soils, vegetation, and a strongly sloping landscape that is exposed to intense thunderstorms between July and September. Consequently, soil erosion and runoff are excessive on some parts of this landscape due to the high erodibility of surface soils. A study was initiated in 1997 to quantify the erodibility of individual soils at the watershed scale, and relate soil erodibility to the composition of suspended sediments. We describe how the soil characterization-erodibility data can be used to assess the relative susceptibility of watershed soils to erosion losses. These data are available on line at the Southwest Watershed Research Center website (http://www.tucson.ars.ag.gov).

1. Introduction

Soil erosion is perhaps a more serious problem in arid and semiarid versus humid regions of the world because the soils are generally shallow and less well-developed with inadequate vegetative cover as a consequence of low annual precipitation and soil water storage capacity. Langbein and Schumm (1958) indicated that under natural rangeland vegetation, maximum erosion occurs at annual precipitation rates of 25 to 38 cm, as essentially no runoff occurs at average annual precipitation rates below 25 cm. When annual precipitation exceeds 38 cm, vegetative cover is sufficient to minimize erosion relative to bare soil conditions. Thus, irrespective of anthropogenic effects, soil susceptibility to erosion losses is closely related to soil development. The extent to which soils formation proceeds in terms of profile development is determined by the five factors of soil formation (climate, organisms, slope, parent material, time) according to Jenny (1941). Of these five factors, Jenny (1980) considered climate to be the most influential due to its control over the rate of physical and chemical processes (Martens et al., 2005).

The distribution of soils in the Walnut Gulch Experimental Watershed in southeastern Arizona is largely determined by the composition of the geologic parent material from which the soils formed through weathering processes. In this regard, the Walnut Gulch Basin is formed on Precambrian to Tertiary-age rocks consisting of sandstone and conglomerates, limestone, volcanics, granodiorite, and quartz monzonite. Limestone influenced, Quaternary alluvium parent material dominates the watershed, occupying approximately 80% of the basin surface (Alonso, 1997). The soils developed from this parent material are generally well-drained, calcareous, gravelly loams with large percentages of rock and gravel at the soil surface (Gelderman, 1970). The other soils in the watershed were formed in alluvium and colluvium from basalt and andesite, and in residuum from coarser textured granodiorite. Generally, these soils are finer textured, shallow, and well-drained.

Soil erosion losses, and indirectly sediment yields, are determined by rainfall characteristics, topography, and vegetative cover. If these factors remain constant as soils change within a watershed, any resulting change in erosion losses can be attributed to differences in soil properties that determine soil erodibility (Bryan, 1969). Soil erodibility is a measure of a soil's inherent susceptibility to erosive forces, and is a function of aggregate stability which is generally determined by properties such as clay content, Fe and Al oxides, and organic C that serve as cementing agents which bind individual soil particles into water stable structural units. The soil clay fraction, in this context, serves as the building block for aggregate stability or soil structure, and the extent to which clay particles disperse in water can be taken as a measure of soil erodibility. Aggregate stability and soil erodibility are inversely related.

At watershed scales, soil erodibility and sediment characteristics are influenced by soil properties that determine aggregate stability. In general, these properties are strongly influenced by soil geomorphology through surface morphometry factors such as slope position, shape, aspect, and gradient (Schoenberger et al., 2002). For example, Franzmeier et al. (1969) reported greater concentrations of organic C on north-facing slopes as a result of lower temperatures and higher soil water contents. In terms of slope position, most studies (Honeycutt et al., 1990; Pierson and Mulla, 1990; Rhoton et al., 2006) report greater organic C on footslope and toeslopes which accounted for the greater aggregate stabilities being recorded in these positions. Particle size distributions and basic cations are also distributed as a function of slope position. Young and Hammer (2000) identified higher silt contents, and lower basic cation concentrations on backslope positions relative to upslope positions. Similarly, Franzmeier et al. (1969) indicated that particle size distributions were coarser on mid-slope positions, and basic cations were concentrated on the lower slope positions.

The Walnut Gulch Experimental Watershed contains several different geologic parent materials that have weathered to produce a variety of soils that occur on a wide range of slope conditions. These rangeland soils are frequently exposed to high intensity rainstorms that have the ability to degrade them to the extent that their sustainability becomes a serious problem on some parts of the landscape. The objectives of this research were to investigate the relationship between parent materials and soils in terms of its affects on soil erodibility, and how this information might be used from the standpoint of designing the most efficient management systems to reduce sediment yields.

2. Methodology

The research was conducted on the Walnut Gulch Experimental Watershed (WGEW) located at Tombstone, AZ (31 deg. 43 min. N. Lat., 110 deg. 41 min. W. Long.). The watershed covers approximately 150 km^2 with elevations ranging from 220 to 1890 m, a mean annual temperature of 17.6 ^{o} C, and an average annual precipitation of 324 mm (Renard et al., 1993).The research was conducted on subwatersheds (SWs) 3, 7, 9, 10, 11, and 15. Each SW was instrumented with a supercritical flume (Renard et al., 1993). Suspended sediments were collected at these flumes, using vertical samplers, in 30.5 cm increments above the floor of the flume for the total flow depth of 122 cm (Rhoton et al., 2006). Soil samples were collected from the watershed on the basis of relative acreage occupied by individual mapping units. A sampling transect length of 1000 m was arbitrarily chosen for each 200 ha of a given soil mapping unit. The transects were positioned using GPS data. Soil samples were collected as a function of slope position, class, and aspect along the transects (Schoenberger et al., 2002). At each selected location, the surface 5.0 cm were sampled at three points, approximately 10 m apart and perpendicular to the slope, and composited to form a single sample. At each sampling location, latitude-longitude, slope position, slope aspect, and slope steepness were recorded.

In the laboratory, soil and sediment samples were air-dried at 60° C, and sieved to < 2 mm. Particle size distribution was determined by standard pipette analysis following overnight dispersion in Na hexametaphosphate (Soil Survey Staff, 1984). The water dispersible clay component of the total clay fraction was also estimated by this methodology using only distilled water as the dispersant. Soil pH was measured in a 1:1 soil/distilled water (v-v) suspension (McLean, 1982). Total C was determined by combusting 0.5 g samples in a LECO CN-2000 carbon-nitrogen analyzer (LECO Corp., St. Joseph, MI). The inorganic fraction of the total carbon was quantified by treating a separate 1 g sample with 5 N HC1 in a sealed decomposition vessel (200 mL) fitted with a rubber septum. Carbon dioxide pressure generated by the acid-decomposition of the sample was measured with a Tensimeter (Soil Measurement Systems, Tucson, AZ) probe inserted through the septum. Pressure readings were converted to C contents using a standard curve, and subtracted from total C to give the organic C content. Quantitative soil color was measured with a Minolta Chroma Meter (Minolta Corp., Ramsey, NJ).

3. Data Availability

Data from this watershed soil and sediment properties research are available on line at the USDA Agricultural Research Service, Southwest Watershed Research Center (http://www.tucson.ars.ag.gov/).

4. Examples of Data Use

These data can be used for assessing the influence of soil properties on several soil erosion and suspended sediment composition parameters at watershed scales. Total clay and water dispersible clay (WDC) data have been used to calculate an aggregation index (AI) as follows: AI = 100 (1-WDC/total clay). This gives an accurate indicator of soil erodibility (Bryan, 1969). Values for soil erodibility are inversely proportional to AI. This approach has been used to determine the effect of parent materials and degree of erosion on the distribution of soil erodibility as a function of surface morphometry factors (slope position, class, and aspect) and the relationship between soil erodibility (Rhoton et al., 2007) and suspended sediment properties (Rhoton et al., 2006). For example, many of the soils in SW 7 on the WGEW were formed on igneous residuum (i.e., granite, granodiorite, porphyry, quartzite) which is considerably more resistant to weathering than the limestone comprising the alluvium in most other SWs. As a result, soils formed on these parent materials are coarse-textured, and contain the lowest clay and organic carbon contents in the WGEW. Since relatively high concentrations of clay and organic carbon are required for a high percentage of water stable soil aggregates and, thus, a high level of resistance to erosion, the soils formed on SW 7 parent materials are expected to have a lower AI, or a relatively high erodibility value. By contrast, many of the soils in SW 9 were formed by the weathering of fine-grained, igneous parent materials (andesite, basalt) that contain more weatherable minerals. The soils formed from these parent materials contained the greatest concentrations of total clay and organic carbon, and the highest average AI value (31.9) in the WGEW. The lowest average AI (18.0) was recorded for the soils in SW 3.

Using clay contents of the suspended sediments, relative to the soils, as an indicator of actual erodibility, we found that the greatest average clay enrichment ratio (1.67) occurred in SW 3, and the lowest (1.02) in SW 9. Thus, SW 3 had the most highly erodible soils in the WGEW, and SW 9 had the least erodible. In terms of slope factors, the least erodible soils in the WGEW were identified on the steepest slopes, in toeslope positions, and on the more north-facing slopes in conjunction with maximums for clay and organic C contents.

As previously indicated, the data have been used to determine the distribution and transport characteristics of C in the WGEW (Rhoton et al., 2006). This research demonstrated that the distribution of soil organic C in the watershed is closely related to differences in parent material and degree of erosion among SWs as these factors determine the status of soil water and fertility. Relative to slope class, organic C was most concentrated on slopes greater than 9%, where clay contents were generally higher, and on lower backslope and toeslope positions where runon contributions are a factor. Organic C contents were seemingly equally divided between north- and south-facing slopes in Walnut Gulch. The watershed soils and suspended sediment differed considerably relative to C contents. Total and organic C contents in the sediment averaged 1.8 and 2.1 times greater than their respective watershed soils. Further, the results indicate that soil organic C is being transported predominately as silt-size (50-2 µm) materials, and the greatest losses are occurring on those soils with the lowest AI.

5. References

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