Geoderma 279 (2016) 149–164

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

The distribution and genesis of eroded phase soils in the conterminous United States

Nicolas A. Jelinski *, Kyungsoo Yoo

Department of Soil, Water and Climate, University of Minnesota-Twin Cities, 1991 Upper Buford Circle, Saint Paul, MN 55108, United States

ARTICLE INFO

Article history:
Received 2 January 2016
Received in revised form 9 May 2016
Accepted 22 May 2016
Available online 14 June 2016

Keywords:
Soil surveys
Soil erosion
Soil profiles
Agriculture
Topography

ABSTRACT

The delineation and mapping of eroded phases of existing soil series has been an important activity throughout the history of soil survey activities in the United States, with implications for land management, crop production and the estimation of historical sediment losses and fluxes. An analysis of the SSURGO database shows that 462,979 km^2 of eroded phase soils (16% of which were classified as severely eroded) are mapped in the conterminous United States, with 9% of 2013 cultivated lands occurring on eroded phase soils. Eroded phases of 2265 soil series in 9 soil orders (excluding Gelisols, Oxisols and Histosols) have been identified and mapped. Examining the distribution of eroded phase soils within survey-independent large-scale physiographic (EPA Level III Ecoregion) boundaries reveals consistent patterns in land-use histories and eroded soils, and that the pattern and distribution of eroded phase soils at regional to continental scales are responsive to the five soil forming factors. The proportion of ecoregion land area mapped as eroded phase was significantly affected by topography, with eroded phase soils peaking in ecoregions with topographic ruggedness indices (TRI, a normalized elevation difference index) between 1 and 2. Among TRI groups, the proportion of total ecoregion land area mapped as eroded phase was significantly related to the historical maximum cultivation intensity, while among a subset of ecoregions with significant histories of cultivation, eroded phase proportion was related to the rainfall-runoff erosivity (RUSLE R-Factor). Of the 2265 named soil series with mapped eroded phases, 73% had family particle size classes of fine, fine-loamy and fine-silty which corresponds with the peak in the RUSLE erodibility factor (K) with respect to particle size. Lastly, ecoregions with histories of significant cultivation for more than 100 years had greater proportions of their land area mapped as eroded phase. These results suggest that despite morphological constraints and subjective factors in the delineation of eroded phases, these soils should be viewed as unique pedological entities that hold lasting value for understanding the effects of accelerated erosion on soil morphology, crop production, and ecosystem services.

1. Introduction

Understanding and reducing the extent and impact of soil erosion remains one of humankind's most pressing challenges (Lal, 1998; Pimentel and Burgess, 2013). In an era when solutions to food security, human health, water quality and climate change are tied ever closer to stewardship of the soil resource (Pimentel, 2006; Quinton et al., 2010; Brevik and Burgess, 2012; Lal, 2013), average rates of soil loss in managed systems tend to be 1–3 orders of magnitude greater than rates of soil formation in natural ecosystems (Montgomery, 2007). The net impact of this accelerated loss is unprecedented, even on geologic timescales (Wilkinson and McElroy, 2007).

Both the on-site and off-site impacts of soil erosion carry significant agronomic, economic, environmental, and societal costs (Pimentel et al., 1995; Graves et al., 2015). In the United States alone, estimates of the economic impacts of soil erosion range from $500 million to $44 billion per year (Telles et al., 2011). These impacts typically increase with increasing erosion extent and cumulative erosion severity (Robison, 1977; Bakker et al., 2004; Fenton et al., 2005, Heathcote et al., 2013). Therefore, in addition to data on current erosion rates, understanding the full magnitude of these impacts requires knowledge of the cumulative effects and historical legacy of soil erosion.

Recording the prevalence and severity of the cumulative impacts of soil erosion has been a focus of the United States National Cooperative Soil Survey through the mapping of eroded phases of soils (Soil Survey Staff, 1993; Olson, 1994). The morphological criteria used to define eroded phases are typically indicators of soil profile truncation or soil loss, including changes in soil properties or the depth of certain

* Corresponding author.

http://dx.doi.org/10.1016/j.geoderma.2016.05.015
0016-7061/

key morphological features (Soil Survey Staff, 1993). For this reason, the eroded phases of existing soil series are best understood as a subset of erosion-affected soils, occurring predominantly on hillslope positions characterized by *soil loss* (summits, shoulders and backslopes) that exhibit *morphological* evidence of *accelerated* erosion, defined as erosion greater in magnitude and shorter in timescale than background or *natural* erosion rates (i.e. rates occurring under prevailing climatic, topographic and biotic forcings) (Soil Survey Staff, 1993; Montgomery, 2007). In all cases, the morphological changes that have occurred in eroded phase soils must be understood in the context of a comparative reference state (Olson, 1994). Developing an appropriate conceptual model for the reference state can prove difficult, particularly in intensively cultivated landscapes, where undisturbed soils are rare and those that are left may have biased properties (Daniels, 1987; Kreznor et al., 1989; Mokma et al., 1996; Olson et al., 2013). The description, classification, and delineation of eroded phases at fine scales thus requires an integrative understanding of the variability in depth of key morphologies or material layers, pedon morphologies, and soil-landscape relationships (Olson and Beavers, 1987; Wilson et al., 2010).

1.1. Erosion terminology in soil survey

Important terminology for interpreting the distribution of eroded phase soils in soil survey is the distinction between *erosion types*, *erosion classes*, and *erosion phases* (Soil Survey Staff, 1993). Only erosion phases are ultimately identified and delineated as discrete map units, but erosion types and classes are closely related to phase and are integral to phase development and identification in most cases.

Erosion *type* refers to the major process or agent responsible for soil erosion and is grouped into water (sheet, rill, gully, and tunnel), wind, and colluvial (i.e. mass movement or tillage erosion) categories. Erosion *classes* are an estimate of the degree to which accelerated erosion has removed material from the upper portion (determined as the estimated thickness of the reference A and or E horizons) of the soil profile. Finally, erosion *phases* (as with other phase designations in soil survey) are recognized on the basis of differences in potential use, management or performance (Soil Survey Staff, 1993). Erosion classes and phases are generally closely linked because most soils have a large number of physical and chemical properties that are depth-dependent and therefore affected by accelerated erosion (Larson et al., 1985).

The Soil Survey Handbook defines 3 recognized water erosion phases (slightly eroded, moderately eroded and severely eroded) and 2 erosion phases specific to wind (eroded (blown) and severely eroded (blown)), and gullied lands when gullies occupy more than 10% of a map unit. Slightly eroded phases are generally associated with little to no morphological change or profile truncation and are not generally distinguished from uneroded soils in most survey areas. Conversely, moderately eroded phases (or simply eroded phases in most surveys) and severely eroded phases typically require changes in land use intensity, extensive reclamation or property restoration efforts, and exhibit reduced productivity or engineering limitations (Soil Survey Staff, 1993).

1.2. Objectives

Despite the potential of the distribution of eroded phase soils to reveal important information regarding land use histories and the cumulative impacts of soil erosion in the United States, no study has comprehensively investigated these soils as a unique pedological group on a continental scale. The objectives of this study were therefore to (i) determine the extent and spatial distribution of mapped eroded phase soils in the conterminous U.S., (ii) compare the distribution of eroded phase soils by political boundary, physiographic boundary, and across cultivated lands, (iii) analyze the distribution of eroded phase soils with respect to factors related to their genesis and mapping and (iv) revisit the implications of eroded phase soils and the importance of mapping efforts.

2. Methods and data sources

2.1. Distribution of eroded phase soils in the conterminous U.S

The Soil Survey Geographic (SSURGO) database (Soil Survey Staff, 2014a) was utilized in state tiles to map the distribution of eroded phase soils in the conterminous United States. State databases were mined for map unit names of SSURGO polygons containing the word “eroded” (case insensitive), indicative of eroded phase map units, “gullied” (case insensitive), indicative of gullied phases or complexes, and “blown” (case insensitive), indicative of wind eroded units using standard SQL queries in ArcGIS 10.2 (SQL query text provided in Supplementary Text). Slightly and severely eroded polygons were extracted from the database by querying the subset of map units containing the word “eroded” with the words “slight*” or “severe*” (wild card, case insensitive). Checks on land area and land area standards utilized data from the U.S. Census Bureau (U.S. Census Bureau, 2010). SSURGO data coverage contains inland water bodies as unique map units, and we therefore distinguish between total land area (independent of the area mapped; U.S. Census Bureau, 2010) and the total non-water mapped area (data contained in the SSURGO database, excluding “Water” map units) (Table S1).

Polygon map unit names in each state were combined to determine the total number of unique eroded map units (inclusive of slope class and additional phase names (i.e. stony/rock/etc) for each named series). The series names for each map unit (and the first named occurring series in a complex) were extracted and queried against the Official Series Description Database (Soil Survey Staff, 2014b). Taxonomic information and family textural classifications were extracted from this list of series names.

We sought to examine the distribution of eroded phase soils with respect to physiographic boundaries that were independent of survey activities to enable a robust analysis as unaffected by subjective mapping factors as possible. Because survey activities have been aligned with both political (county and thus state) and Major Land Resource Area (MLRA) boundaries, we utilized the independently delineated EPA Level III Ecoregions as our physiographic unit of analysis (Omernik, 1995; USEPA, 2013). We chose Level III Ecoregions because the eighty-five EPA Level III Ecoregions in the conterminous United States (Fig. S1) are of an appropriate scale for continental analysis, in contrast to Land Resource Regions ($n = 20$), MLRAs ($n = 156$), and EPA Level I ($n = 10$), Level II ($n = 19$) and Level IV ($n = 977$) Ecoregions (Omernik, 1995). Due to size constraints, ecoregion names are not provided directly on the main figures, however an ecoregion key is provided in the supplementary files (Fig. S1), which can be referred to if direct identification of ecoregion names and locations are necessary.

The intersection of eroded phase polygons and cultivated/uncultivated pixels in the 2013 National Cultivated Layer (USDA, 2013, 30 m resolution) was used to determine the extent of currently cultivated and uncultivated lands on mapped eroded phase soils. The 2013 National Cultivated Layer is a binary (cultivated or uncultivated) spatial raster dataset generated by combining the previous five years (2009–2013) of the USDA-NCSS Cropland Data Layer (CDL). If a pixel was cultivated in at least two of the previous five years it was assigned to the cultivated class (USDA, 2013).

A global 30-arc second raster of terrain ruggedness (Gruber, 2012) was utilized to determine the average Terrain Ruggedness Index (TRI) for each Level III Ecoregion, as a measure of topographic heterogeneity. TRI is a scaled version of a neighborhood area normalized elevation difference (Melton, 1965; Gruber, 2012) and can be used to broadly classify global landscapes (at 30-arc second resolution) into flat (i.e. Ganges-Indus Plains and Hudson Bay Lowlands; TRI = 0–1.5), undulating (i.e. Piedmont and non-glaciated Northern Plains of the U.S.; TRI = 1.5–2.5), hilly (i.e. the Central Uplands of Western Europe and Germany and the U.S. Midwestern Driftless Area; TRI = 2.5–3.5), mountainous (i.e. much of the Appalachian and Rocky mountains; TRI = 3.5–4.5) and rugged (i.e. the cores of the Canadian Rockies, Brooks Range, Alps, and Himalayas; TRI > 4.5) categories.