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Sediment composition for the assessment of water erosion and nonpoint source pollution in natural and fire-affected landscapes

Athena B. Carkovic, Pablo A. Pastén, Carlos A. Bonilla *

Departamento de Ingeniería Hidráulica y Ambiental, Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna 4860, Macul, Santiago, Chile
Centro de Desarrollo Urbano Sustentable CEDEUS, El Comendador 1916, Providencia, Santiago, Chile

HIGHLIGHTS

- Sediment composition equations were tested on soils from the Chilean Patagonia.
- Equations over- and under-estimate fine and large sediment particles.
- New equations were built to predict sediment composition in uncultivated soils.
- Primary sand and large aggregates are especially well predicted with the new equations.
- Additionally, these equations provide even better aggregate composition estimates.

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ABSTRACT

Water erosion is a leading cause of soil degradation and a major nonpoint source pollution problem. Many efforts have been undertaken to estimate the amount and size distribution of the sediment leaving the field. Multi-size class water erosion models subdivide eroded soil into different sizes and estimate the aggregate's composition based on empirical equations derived from agricultural soils. The objective of this study was to evaluate these equations on soil samples collected from natural landscapes (uncultivated) and fire-affected soils. Chemical, physical, and soil fractions and aggregate composition analyses were performed on samples collected in the Chilean Patagonia and later compared with the equations' estimates. The results showed that the empirical equations were not suitable for predicting the sediment fractions. Fine particles, including primary clay, primary silt, and small aggregates (<53 μm) were over-estimated, and large aggregates (>53 μm) and primary sand were under-estimated. The uncultivated and fire-affected soils showed a reduced fraction of fine particles in the sediment, as clay and silt were mostly in the form of large aggregates. Thus, a new set of equations was developed for these soils, where small aggregates were defined as particles with sizes between 53 μm and 250 μm and large aggregates as particles > 250 μm. With r^2 values between 0.47 and 0.98, the new equations provided better estimates for primary sand and large aggregates. The aggregate's composition was also well predicted, especially the silt and clay fractions in the large aggregates from uncultivated soils ($r^2 = 0.63$ and 0.83, respectively) and the fractions of silt in the small aggregates ($r^2 = 0.84$) and clay in the large aggregates ($r^2 = 0.78$) from fire-affected soils. Overall, these new equations proved to be better predictors for the sediment and aggregate's composition in uncultivated and fire-affected soils, and they reduce the error when estimating soil loss in natural landscapes.

1. Introduction

Water erosion is one of the leading causes of soil degradation (Lal, 2001; Oldeman, 1992), and also a major nonpoint source pollution problem (Yang et al., 2003), as it leads to preferential removal of fine particles (Pimentel et al., 1995; Yang et al., 2003). Organic matter and pollutants bind preferentially to fine particles (Aksoy and Kavvas, 2005; Morgan and Quinton, 2001), which causes eroded sediment to contain higher amounts of organic matter and nutrients than the topsoil from which it was derived (Young, 1989). Thus, nonpoint source pollution causes major water quality issues, which turn into critical environmental, social, and economical problems (Borah and Bera, 2003).

Reducing water erosion to maintain soil sustainability usually requires estimating soil losses as a function of many factors such as climate, topography, soil, vegetation and human activities, including tillage and conservation practices (Kuznetsov et al., 1998).

Numerous erosion models have been developed with the purpose of reducing water erosion, but most of them do not provide the particle size distribution, which is required to estimate the fate and transport

* Corresponding author.
E-mail address: cbonilla@ing.puc.cl (C.A. Bonilla).

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of pollutants. In addition, the suspension time and transport distance of the particles depend on the particle's settling velocity, which is a function of its size, density, shape and moisture content (Lovell and Rose, 1988a,b). Thus, a single size class model is usually not a robust predictor for sediment yield and composition (Sander et al., 2011).

Some water erosion models, called single-size class, work with a mean particle size, while other models, called multi-size class, operate with a sediment size distribution (Aksoy and Kavvas, 2005). Examples of the multi-size class approaches are the Water Erosion Prediction Project (WEPP) model (Nearing et al., 1989; USDA, 1995), the Revised Universal Soil Loss Equation, version 2 (RUSLE2) model (USDA-ARS, 2008), and the Precision Agricultural Landscape Modeling System (PALMS) model (Bonilla et al., 2007). In all of them the sediment is divided into five size classes based on empirical equations developed by Foster et al. (1985), which relate the soil matrix texture to the sediment composition at its point of detachment. In these equations, the sediment is divided into primary particles (clay, silt, and sand) and small and large aggregates based on field data collected from agricultural soils in the USA.

Soil aggregates, which are predicted in these multi-size class models, are clusters of primary particles that cohere to each other more strongly than with the other surrounding soil particles (Angers and Caron, 1998; Kemper and Rosenau, 1986). Aggregate formation depends on chemical, physical and biological factors (Mataix-Solera et al., 2011), and a large aggregate's stability is usually related to soil quality because is a key factor controlling topsoil hydrology, crust development and soil erodibility (De Ploey and Poesen, 1985; Le Bissonnais and Arrouyais, 1997).

Tillage operations may cause soil degradation and the loss of nutrients, organic matter soil aggregates, and macroporosity (Brady and Weil, 2002). Similar effects are also produced by forest fire events (Certini, 2005) or environmental land use conflicts (Valle Junior et al., 2014). In the case of wildfires, soil properties can experience short-term, long-term or permanent fire-induced changes (Certini, 2005) or may remain unaffected at depths below the upper few centimeters (DeBano, 2000; Knicker, 2007; Neary et al., 1999). Because the equations developed by Foster et al. (1985) were derived from agricultural soils, their use on soils with different conditions, fire-affected or uncultivated, may lead to unreliable estimates on the erosion process.

The objective of this study was to evaluate the empirical equations developed by Foster et al. (1985) on natural landscapes and fire-affected soils from the Serrano river basin and, when necessary, to develop a new set of equations more suitable for these conditions. With this purpose, soil samples were taken from a natural area located in the Chilean Patagonia and compared with the sediment composition computed with the equations developed by Foster et al. (1985). Because of the results of this analysis, a new set of equations was developed for uncultivated and fire-affected soils.

2. Materials and methods

2.1. Study area and soil samples

The Serrano river basin is located in the Chilean Patagonia (Fig. 1) between 50°33′ S and 51°32′ S and between 72°10′ W and 73°34′ W (Bonilla et al., 2014). It has an irregular topography interrupted by major lacustrine bodies. The average annual precipitation in the study area ranges from 200 mm yr^{-1} on the eastern side to 1000 mm yr^{-1} on the western side. The mean annual temperature is approximately 7 °C, with a minimum temperature of 3 °C in August and a maximum of 13 °C in January (DGA-MOP, 1987). The dominant vegetation is the native evergreen forest in the western sector and bushes and peaty scrubland in the cooler areas (Michea et al., 1996). There are nearly no human settlements, except for tourism and hotel facilities. The main four soil types are Luvic Phaeozems (28% of the basin area), Dystric Cambisols (24%), Lithosols (13%), and Eutric Cambisols (10%). The rest of the basin area corresponds to water bodies, rocky areas, glaciers and snow (IUSS Working Group WRB, 2007). Half of the basin belongs to the

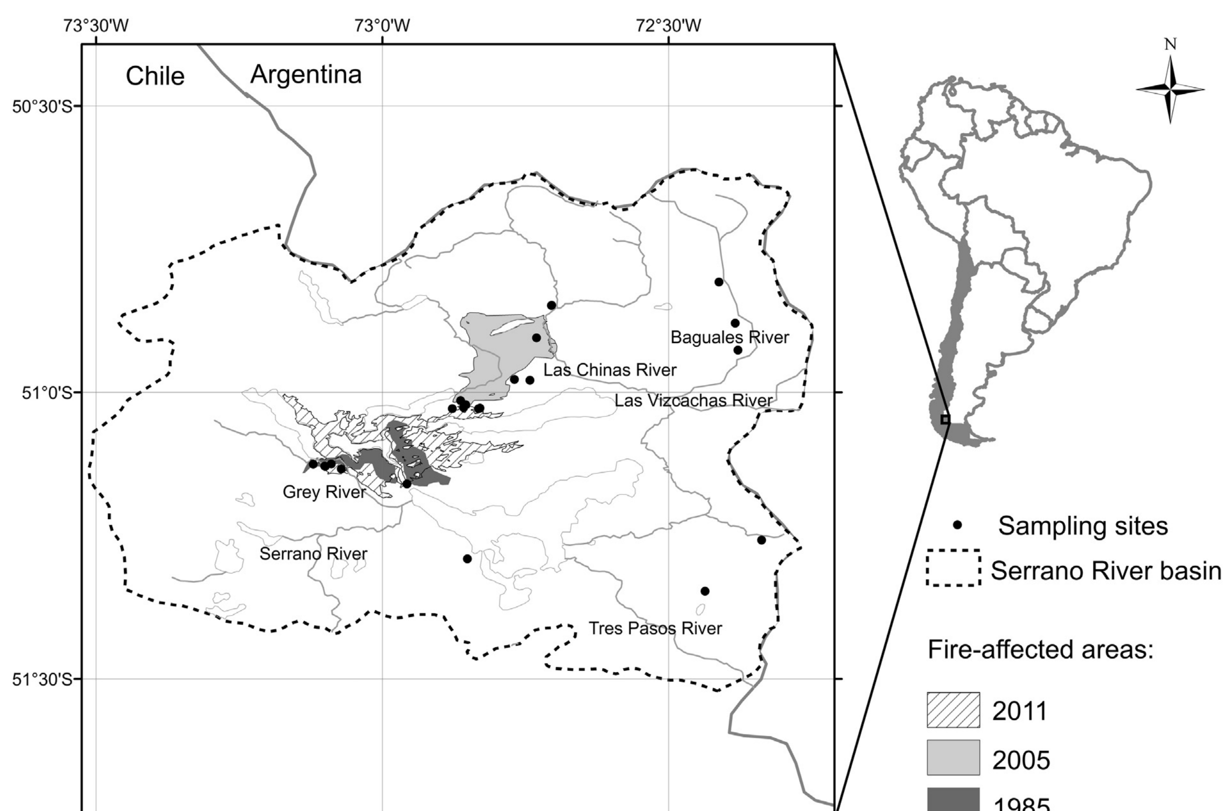

Fig. 1. Location of the Serrano river basin, sampling sites, and fire-affected areas after the three major fires.