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Soil erosion as a function of different agricultural land use in Rio de Janeiro

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ABSTRACT

Accelerated erosion in the mountainous agricultural area of Rio de Janeiro has caused significant environmental degradation and financial loss. Consequently, quantifying and analyzing soil erosion under different agricultural systems in the region is essential for adoption of specific and effective soil conservation practices. Gerlach-type runoff-erosion plots were used to collect runoff and measure sediment yield from four different land management areas (olericulture with conventional tillage, pasture, forest restoration system and native rainforest). Physicochemical analyses, soil profile description and permeability assays were employed to reveal the erosive processes. Soil water retention curves were used to infer soil pore size distribution, which affects permeability and runoff. We observed that erosion increases with conventional tillage practices, as was revealed in the experimental olericulture plot, where erosion of 14,779 kg ha^{-1} was measured in the period of March 2008–January 2009, compared with only 4.5 kg ha^{-1} in the pasture plot in the same period, mainly because of the decrease in soil particle cohesion and infiltration in association with poor vegetation cover.

1. Introduction

Agricultural management systems without soil conservation practices increase erosion, contributing to siltation and eutrophication of water bodies. Moreover, lack of soil conservation practices can lead to desertification of fertile areas. About 1.5 billion hectares, or approximately 10% of the world's land surface, have been degraded by erosion (Angima et al., 2003).

Conventional tillage alters the intrinsic physical properties of the soil, such as soil structure, porosity, pore-size distribution, aggregation, particle size distribution, water retention capacity and permeability. These soil properties have direct influence on erosion and runoff and must be investigated. Soil classification, mineralogy, organic matter content and vegetation cover are key issues to understand erosive processes. Soil structure disruption alters porosity, pore-size distribution and aggregation. Holden (2009) reported that conventional tillage reduces macroporosity interconnection due to soil structure disruption. Conventional systems pulverize the topsoil, making it more susceptible to erosion (Tavares Filho et al., 2010). Souza (2003) observed high soil loss and runoff from land preparation in tomato fields in a mountainous agricultural area of Rio de Janeiro. Swanepoel et al. (2013) observed an adverse effect on physical resistance and soil microstructure strength in the conversion of virgin soil to minimum-till Kikuyu–*ryegrass* pasture after 19 years of land use. Susceptibility to erosion depends directly on the cohesive strength of soil binding factors. Wuddivira et al. (2013) explained the relevance of organic matter content in increasing the cohesion between clay particles. Good soil aggregation reduces erodibility. Aggregation is increased by organic matter input, minimum soil disturbance and decrease in organic carbon loss by erosion (Bronick and Lal, 2005).

Prado (2011) stressed the key role of mountainous regions in the supply of water, and its intrinsic relationship with a system of sustainable agricultural production. In this sense, this study focused on the "Córrego Sujo Basin", where conservation agriculture practices are not adopted. Erosion in this agricultural basin is

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responsible for the siltation of the main rivers in the mountainous region of Rio de Janeiro state, and can lead to floods due to reduction of river depths. Vieira and Cunha (2008) evaluated the changes in channel morphology of third-order streams, tributaries of the Paquequer River, located in Teresópolis in the mountainous region of Rio de Janeiro. Vieira and Cunha (2008) concluded that the removal of sediment in tributaries contributes to sedimentation in the main river, and the expansion of the capacity of the channel by dredging or cross-section enlargement in fact creates a section with greater sediment accumulation. The problem of sedimentation is passed downstream, and is not considered upstream where the process begins. Conscientious planning has to consider the watershed as a whole. Floods and landslides in 2011 led to the loss of a thousand lives in this region.

The aim of our work was to investigate soil erosion on agricultural land under different vegetation covers and land use, to quantify and better understand the erosive processes in the mountainous region of the state of Rio de Janeiro, considering the deforestation of the Atlantic Forest due to livestock grazing and olericulture.

2. Materials and methods

2.1. Location, site description and climate

The investigation was conducted in Córrego Sujo Basin (53 km^2). This basin is characterized by intensive agriculture and large pasture areas. Córrego Sujo Basin is situated in the municipality of Teresópolis in Rio de Janeiro, with an approximate altitude of 870 m, and comprises nine sub-basins. The coordinates of the sub-basin study area are 22° 12′ 52” S and 42º 48' 39” W. Córrego Sujo (Sujo Steam) is a tributary of Bengalas River, which drains into the Paquequer River. The forest fragmentation is composed of secondary forests, remnants of the Atlantic Forest, in different successional stages with floristic domain of Dense Ombrophilous Montane Forest, which is an ecosystem of evergreen forest with closed canopy and variegated vegetation with abundant and well-distributed rainfall. These fragments occupy the top of the mountains. The region has been degraded by farming and cattle grazing, leaving only traces of primary forest. Soil management does not follow conservation practices such as contour plowing. The plant cover of the cultivated area varies greatly due to the intensive rotation of vegetable crops. The climate type is humid mesothermal with little water deficit, with a well-defined dry season from May to August. The temperature is hot in summer and mild in winter. The differences between maximum and minimum daily temperatures are higher in winter.

2.2. Soil profile description

The study of erosion requires a detailed soil survey, since each class of soil has specific erodibility. The predominant soils in the region are Cambisols, usually occurring in association with Red–Yellow Oxisol in the mountainous relief, and Entisols and rock outcroppings on the steeper slopes (EMBRAPA, 2006). The morphological attributes of the horizons follow the standards of the National Service for Soil Conservation and Research (EMBRAPA, 1988). The soil profile description was conducted in a location near plots of pasture, forest restoration and native rainforest. The profile description was based on a geomorphologic analysis of the area. It was not possible to describe the soil profile in the olericulture plot because the topsoil had been removed in this plot.

2.3. Soil characterization and physicochemical analyses

Disturbed soil samples were collected to analyze the physicochemical properties of the soil to determine the parameters that influence the erosive process, such as soil texture and granulometric curves. Six disturbed soil samples of the horizons from the soil profile were collected for laboratory characterization. Twenty-four disturbed soil samples were collected from the four erosion plots at three depths (30–40, 60–70 and 90–100 cm), with two replications at each depth. These depths were chosen to represent surface, subsurface and bottom layers of the soil profile. The soil samples of the pasture, forest restoration system and native rainforest plots at the depths of 30, 60 and 90 cm corresponded, respectively, to the A2, BA and Bw1 horizons. The soil samples from the olericulture plot could not be correlated to these horizons due to extensive land degradation.

Granulometric analyses were carried out according to the ASTM D422-63 (2007) standard to determine soil texture and specific gravity. To evaluate aggregability, 24 samples in the presence of a deflocculant (sodium hexametaphosphate) with pH between 8 and 9 were first analyzed. Afterwards, six separate samples were analyzed in the absence of the deflocculant. Atterberg limits were determined to assess soil plasticity according to ASTM D4318-10 (2010). The physicochemical analyses were performed following the method described by EMBRAPA (2011) and EMBRAPA (1979). Clay minerals were identified by X-ray diffraction using a Rigaku Miniflex diffractometer. Eight clay samples from the four plots at depths of 30–40 and 90–100 cm were analyzed. Grades of weathering–leaching were given by K_i and K_r indexes, calculated by Eqs. (1) and (2).

$$K_i = \frac{SiO_2 \ \ g\ (100\ g)^{-1} \times 1.70}{Al_2O_3 \ \ g\ \ (100\ g)^{-1}} \tag{1}$$

$$K_r = \frac{S_iO_2 \ \ (100\,g)^{-1}/0.60}{\left(Al_2O_3 \ \ g(100\,g)^{-1}/1.02\right) + \left(Fe_2O_3 \ \ g\ (100g)^{-1}/1.60\right)} \tag{2}$$

$SiO_2\,g\,(100\,g)^{-1}$, $Al_2O_3\,g\,(100\,g)^{-1}$ and $Fe_2O_3\,g\,(100\,g)^{-1}$ were determined by physicochemical analyses according to a specific method using sulfuric acid described by EMBRAPA (1979). Low K_i and K_r indexes refer to more weathered soils or horizons.

2.4. Permeability assays and characteristic curves

Soil permeability tests were performed to obtain infiltration capacity. Laboratory permeability tests with constant head were performed in nine undisturbed soil samples, collected at depths of 30–35, 60–65 and 90–95 cm using volumetric rings of 100 cm^3 (Kopecky ring), from the pasture, forest restoration and native forest erosion plots due to lower clay percentages, in accordance with ASTM D2434-68 (1968). Permeability assays on three samples from the olericulture plot, which had higher clay concentrations, were conducted with a falling head method (ASTM D5084-10, 2014). Souza (2003) stated the importance of studying the water flow not only in the surface layers, but throughout the soil profile because of the potential influence of the deeper layers' properties on infiltration. The soil samples in the volumetric rings were placed in permeameters immersed in water for a minimum of 72 h to allow saturation.

The soil–water characteristic curves (SWCCs) were obtained using the filter paper method (ASTM D5298-03, 2003) in eight undisturbed soil samples collected at 30–35 cm depth (two samples for each plot). The samples were saturated and gradually air dried to obtain at least seven water content values with corresponding suctions to construct the SWCCs. Three filter paper sheets were put in direct contact with each side of the soil sample in a Kopecky ring, and then wrapped in a plastic film and aluminum foil and left to rest in a humidity chamber in order to keep the temperature stable, for a period of 24 days. After this time, the