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Tracing sediment sources in two paired agricultural catchments with different riparian forest and wetland proportion in southern Brazil

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ABSTRACT

Riparian forest and wetlands act as a barrier that can reduce sediment transfer from crop fields to the water bodies. The present study investigated the sediment source contribution in two paired agricultural catchments with different proportions of riparian vegetation and wetlands, and similar proportion of crop fields, by using the fingerprinting approach. This study was carried out in two catchments from an agrarian reform settlement in Southern Brazil (JC80 – 80.2 ha, and JC140 - 142.6 ha). Sediment sources evaluated were crop fields, streambanks, unpaved roads, and grasslands. Suspended sediments samples were collected during nine storm-events from April 2011 to October 2013. The average contribution of sediment sources in JC80 was 16 ± 19% crop fields, 49 ± 26% streambanks, 15 ± 14% unpaved roads, and 20 ± 22% grasslands, while in JC140 it was 11 ± 12% crop fields, 23 ± 14% streambanks, 41 ± 19% unpaved roads, and 25 ± 14% grasslands. Preserved riparian vegetation, wetlands, and artificial ponds promote sediment trapping and reduce connectivity between cropland and streams, decreasing the amount of sediments transferred to the water bodies. Moreover, the findings from this work also suggest that unpaved road contributions depend on the number of junctions between roads and the stream network.

1. Introduction

Soil erosion is a well-known problem that generates both on-site and off-site effects. On-sites problems are related to the decrease of soil fertility and water retention capacity which have direct effects on crop productivity (Evans, 2005; Li et al., 2007; Li and Shao, 2006; Quinton et al., 2010; Yao et al., 2009; Zhang et al., 2004). Off-site problems are related to the siltation of dams, reservoirs and channels (Kondolf et al., 2014), as well the degradation of aquatic environments caused by the accelerated transport of nutrients (Martínez-Carreras et al., 2012) and pollutants to the water bodies.

In Júlio de Castilhos, as in most part of southern Brazil, areas under soybean (*Glycine max*) cultivation are often managed on crop-livestock integration under no-tillage system. In these areas, oats (*A. strigosa*) and ryegrass (*L. multiflorum*) are cultivated in winter for cattle feeding. Crop fields are cultivated without the use of mechanical runoff control measures and without the application of crop rotation. The lack of physical barriers and the sparse vegetation cover of the soil enhance soil losses from crop fields. Moreover, integrated crop-livestock system under NT with inadequate management cause topsoil compaction (Bell et al., 2011; Collares et al., 2011; Sharrow, 2007) and/or reduce the soil vegetation cover for summer crops, facilitating water runoff and sheet erosion. According to study performed by Kurz et al. (2006) in Ireland, the presence of cattle had a longer lasting effect on the soil hydrological parameters than on the nutrient concentrations measured in overland flow.

In Júlio de Castilhos, Rio Grande do Sul state, Brazil, Capoane (2011) showed using geoprocessing tools and remote sensing, that 12 years after the implementation of the land reform settlement, there was major changes on geomorphology and on hydro-sedimentological dynamics in both catchments. It was observed significant increase in road network, without any planning, allocating roads in wetlands and following the slope line (Capoane and Rheinheimer, 2012). Most wetlands were drained in order to incorporate the area in the production system for grain or cattle grazing. The proportion of the riparian area was little changed, however, with the fragmentation of the area into smaller lots increased the animal trampling in these areas, hindering the natural regeneration of the vegetation. Moreover, the intense animal trampling in certain places lead to direct connections of water

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and sediment flows from crop fields and pastures into the drainage network, resulting in problems with water quality (Capoane and Rheinheimer, 2013).

In a subsequent study in Júlio de Castilhos, Pellegrini (2013) monitored variables such as rainfall, water flow and turbidity (to estimate suspended sediment concentration) in order to evaluate the effects of land use and soil management on the hydro-sedimentological dynamics of both catchments. In this study, it was found that the catchment with more wetlands generated the highest indexes of runoff, but the sediment production was lower. In the catchment with more riparian forest, the water flow was more balanced flow, runoff was lower, and sediment trapping was lower. Furthermore, it was found that the increase in the road network might have potentiated the sediment production in the catchment with the largest area of riparian forest.

In a further study in Júlio de Castilhos, Rasche (2014) evaluated the dynamics of transference and transformation of P in soil, sediment and water in both catchments by using mineralogical analysis, sequential chemical fractionation of P, and kinetics of sorption and desorption of P in soil and sediment (Rasche et al., 2014). The results showed that wetlands are important for sediment retention and, therefore, to reduce P transfer into the water bodies. Moreover, it was found that the roads transfer considerable amounts of sediment, though this material is free of anthropogenic P.

The information generated by these previous studies were important and helped to better understand the hydro-sedimentological dynamics in these catchments. However, there is still great uncertainty about the magnitude of the contribution of the main sources of sediment, which can be assessed by using traceability techniques of sediment, such as fingerprinting approach, which is the purpose of the present study. Therefore, the present study was carried out aiming to investigate the sediment source contribution from different sources (crop fields, unpaved roads, streambanks, and grasslands) during storm-events in southern Brazil by using the fingerprinting approach. The studied paired agricultural catchments (JC80 – 80.2 ha and JC140 - 142.6 ha) had different proportions of riparian vegetation and wetlands.

2. Material and methods

2.1. Study site

Two catchments were monitored at the Alvorada agrarian reform settlement in the municipality of Júlio de Castilhos, geomorphological region of Planalto das Missões, in Rio Grande do Sul State. The total area of the Alvorada settlement is 1569 ha (Fig. 1). Land use has changed dramatically after the establishment of the Alvorada settlement in 1996. Until then, the main production system was extensive cattle under pasture with small areas of crop for cattle feeding. After the implementation of the settlement, >90% of native pastures areas were converted into areas for grain production, mainly soybean and maize (Capoane and Rheinheimer, 2012). The area was expropriated in February 1996, and then divided into 72 lots (Moreira, 2008). The decision to perform these studies in the area was taken in agreement with the INCRA (National Institute of Colonization and Agrarian Reform of Brazil), MDA (Ministry of Agrarian Development), and the settled farmers.

In the area of the Alvorada settlement two study catchments were chosen, for considering different aspects of water resources protection. The total areas of the catchments were 80.2 and 142.6 ha, referred hereafter to as JC80 and JC140, respectively. The JC140 catchment is characterized by the larger presence of riparian forest (10.2%) and lower proportion of wetlands (5.1%) whereas the JC80 has lower proportion of riparian vegetation (1.5%), but it has a large wetland area (18.1%) (Table 1 and Fig. 1).

Both catchments are tributaries to the Upper Jacuí River, which flows into the Jacuí River that supplies water to the metropolitan region of Rio Grande do Sul (RS) state where over 2 million people are living. These are third order catchments (1:10,000) following the criteria introduced by Strahler (1957), i.e. channels that originate from the confluence of two second-order channels and can receive tributaries of second and first orders. The average slope of stream channels is 5.15 and 5.51% in JC80 and JC140, respectively. In JC80, the main channel tends to be rectilinear (sinuosity ratio = 1.01), whereas in JC140 the main channel is meandering type (SI = 1.61).

According to Köppen, the climate is classified as subtropical humid with hot summers and winter with frequent frosts (Cfb type). The average annual temperature ranges from 17 to 20 °C. The average temperature of the coldest month is between 11 and 14 °C and the mean temperature of the warmest month ranges from 23 to 26 °C. The average rainfall is between 1500 and 1700 mm yr^{-1} well distributed throughout the year with 90–110 days of rain (Rossato, 2011). Altitude in both catchments ranges from 431 to 506 m above sea level.

The relief of both catchments is homogeneous, formed generally by well-rounded gentle hills, carved in basic volcanic rocks of the Serra Geral Formation and, to a lesser extent, in sedimentary rocks corresponding to Tupanciretã Formation. The soil types in the catchment according to World Reference Base for soil Resources (WRB) (IUSS Working Group WRB, 2007) are predominantly Acrisols, with some areas of Cambisols, Gleysols, and Leptosols. The main land use in both catchments is annual crops, representing about 64% of the total area (Fig. 1). The second most important land use is grasslands accounting for about 30 and 18% of the total area for the catchments JC80 and JC140, respectively.

Unpaved roads cover about 1.4% of the catchment areas. After the division of the farm into lots by INCRA in 1996, the unpaved roads were built up and down and down the slope, facilitating water flux and becoming an important sub-surface sediment source in these catchments. In addition to the existing natural drainage network in the catchments, there are several artificial ponds that were built for supplying water to livestock as well as for fish farming, especially at JC140.

2.2. Hydro-sedimentological monitoring

The hydro-sedimentological monitoring included precipitation, flow, turbidity and the suspended sediment concentration (SSC). Rainfall was monitored by an automatic meteorological station (volumes recorded every 10 min) and by three rain gauges (DAVIS, model VantagePro 2). The discharge was monitored through two Parshall rails with critical widths of 1.22 and 1.52 m, in the JC80 and JC140 catchment, respectively. The results were recorded in 5 min intervals by a datalogger connected to a limnigraph (pressure sensor – Solar Instrumentação model SL2000) installed in each control section. Next to the rails was installed one turbidity monitor to estimate suspended sediment concentration each 5 min.

Suspended sediment (SS) samples were collected from river flow with a sampler model DH48 through vertical sample integration. In addition, turbidity data were used as an indirect measurement of SSC. The turbidity meter calibration was performed in two steps using protocols of calibration: (*i*) use of Formazin standard solution concentrations 0, 40, 100, 400, 800, 1000, and 3000 Nephelometric Turbidity Unit (NTU), and (*ii*) using SS samples described above obtained during the monitoring of flood events (monitoring campaigns). Suspended sediment yield (SSY) was then calculated by using suspended sediment concentration and discharge for each storm event.

2.3. Sediment source and suspended sediment sampling

Potential sediment sources types were collected in areas where sediment mobilization and transport processes were visible in the study catchments during storm events. Four main sediment sources types were identified in both catchments (JC80 and JC140), namely: (*i*) surface of crop fields, (*ii*) surface of grassland (perennial grasses), (*iii*) unpaved roads (which includes road verges), and (*iv*) streambanks. The samples of potential source material were collected using