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Phosphorus dynamics during storm events in a subtropical rural catchment in southern Brazil

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ABSTRACT

The intensification of agricultural activities increases the transfer of phosphorus (P) to surface water bodies causing a wide range of environmental, social and economic problems, such as eutrophication. This paper describes the dynamics of P loss during rainfall events (intra-event) and between events (inter-event) in a rural catchment with intensive soil use in southern Brazil, emphasizing the relationships of the solutes with the hydrosedimentological variables. The information on the magnitude and the pattern of P transport was obtained during eighth significant rainfall events, in addition to the sampling performed during the baseflow period (between events). During the events, we evaluated the transfer dynamics of the total P (TP), dissolved P (DP), particulate P (PP) and suspended sediment concentration (SSC). Phosphorus (dissolved and particulate) is predominantly lost during events. The concentrations of DP and PP were low in samples collected in the period between events, when groundwater flow predominates. There is predominance of subsurface flow for the total volume of DP drained into the catchment. The hysteresis of TP forms a loop in the counterclockwise direction at the moment the soil is exposed by plowing, due to P transfer from the cropland to the water course. The transfer of P occurred predominantly in the particulate form (88%) due to the high affinity of P with mineral colloids. There was predominance of clockwise hysteresis for TP and SSC during the fallow period and at the beginning of soil mobilization, indicating the presence of P and sediment sources closer to the catchment outlet. However, during the development period of the crop, when the soil was more exposed due to plowing, counterclockwise hysteresis was observed for TP, which indicates a predominance of sources farther from the outlet, such as the cropland. Thus, we believe that efforts towards adopting practices that reduce erosion can contribute to a reduction of P transfer to water sources. Consequently controlling the process of eutrophication.

1. Introduction

The cultivation of tobacco (*Nicotiana tabacum L.*) in southern Brazil is carried out exclusively in small family production units due to the great need for manpower. There are widespread conflicts between crop production, environmental legislation and agricultural aptitude. The crop production system is integrated to the tobacco industry, where the use of fertilizers and agrochemicals often does not follow any agronomic and environmental criteria. The recommended quantities, forms and times of fertilizer application are the same for the more than one hundred thousand producers in southern Brazil, regardless of specific farm-plot factors such as clay content, soil type, or fertilization history. The constant applications of high doses of phosphate fertilizers (well above the export rates by the crops) greatly increase the P content in the soil, decrease the adsorption energy of P (as the most avid P sites are saturated), redistribute the added P in adsorbed fractions with less energy and of greater availability to plants and, consequently, increase the bioavailable quantities when reaching the water sources (Guardini et al., 2012; Horowitz, 2004; Rheinheimer et al., 2000; Rodríguez-Blanco et al., 2010).

This phenomenon is intensified, because tobacco production is set in extremely environmentally fragile areas, either due to sloping to mountainous relief, or to low levels of clay and organic matter or cultivation on shallow soils. In this areas, the soil is tilled before transplanting tobacco seedlings and planting grains. Therefore, long-term sediment traceability studies in Arvorezinha catchment in southern Brazil indicate that more than half of the sediment yield originates from the cropping areas (Tiecher et al., 2015), driving together adsorbed solutes and pesticides. Thus, intensive soil use is increasing the P content in surface waters (Capoane et al., 2015; Li et al., 2015; Mainstone

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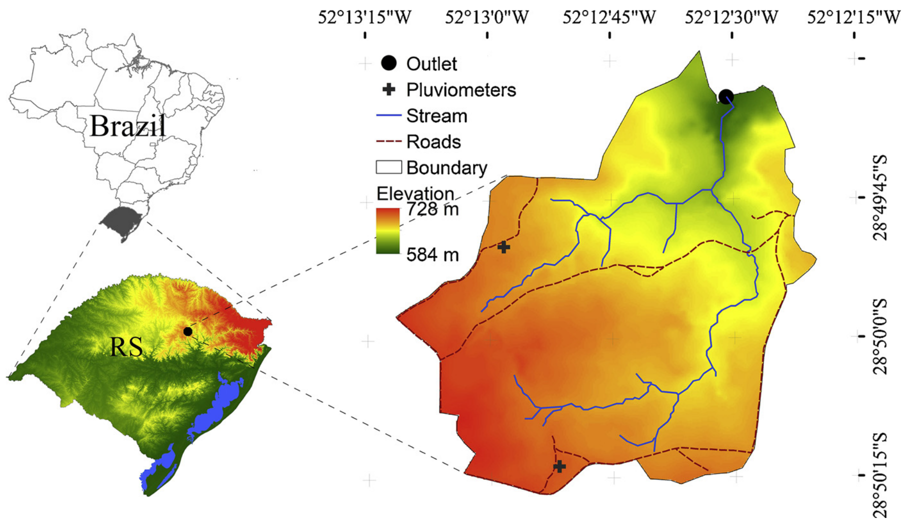

Fig. 1. Location of the Arvorezinha catchment, southern, Brazil.

and Parr, 2002; Sharpley et al., 2015; Withers and Jarvie, 2008), causing problems of eutrophication in land water, since P is a key element in triggering this process (Correll, 1998).

The monitoring of the pattern of P transfer from the terrestrial to the aquatic system is necessary to understand the temporal variability of its trophic state. Due to the irregular and often brief nature of the rainfall events, the greatest discharges of pollution are not monitored and may escape monitoring systems based on seasonal sampling, underestimating the trophic state of the water source (Jones et al., 2012). Therefore, it is important to establish continuous monitoring programs to understand the hydrological regime of the rivers and the dynamics of sediments and solutes transfer or transport in catchments. The inclusion of sampling during the events is necessary, since the largest sediment and total P transfers occur at these times (Horowitz, 2004; Lloyd et al., 2016; Ramos et al., 2015). Estimates show that up to 86 and 92% of sediment and P, respectively, are transported during storm events (Ramos et al., 2015).

The separation of P in dissolved and particulate forms improves the understanding of its dynamics at the catchment scale. Particulate P represents the transported fraction adsorbed to sediments, that is not initially available. However, desorption of the phosphate will occur whenever the equilibrium concentration of the sediment is lower than the concentration present in the water (Pellegrini et al., 2008). Desorption is particularly high under anoxic conditions. Phosphorus dissolved in natural environments is mostly in the form of free phosphate (HPO_4^{-2} and $H_2PO_4^{-}$), fully bioavailable to algae in water bodies (Berretta and Sansalone, 2011).

The concentration of P and most of the solutes present in the environment varies during the rainfall event due to a series of factors, such as the distance from the source to the outlet, its solubility and, consequently, the relationship with surface runoff and/or erosion, dilution or enrichment by subsurface flow (Bowes et al., 2015, 2005; Donn et al., 2012; House and Warwick, 1998; Ide et al., 2008; McDiffett et al., 1989). In general, the temporal variation along the event does not correspond directly with the variations of discharge or even with sediment concentration, resulting in poor relationships between sediment and P concentration with discharge. Therefore, it is necessary to establish continuous monitoring programs to understand the hydrological regime of the rivers and the dynamics of sediments and nutrients in the river basins. Moreover, due to the sporadic and often low-duration nature of rainfall-flow events, pollution peaks may not be accounted for when monitoring systems based on seasonal sampling are used.

The discharge-sediment and discharge-solute relationships usually present a cyclic form known as hysteresis (Lloyd et al., 2016). Several studies point to the occurrence of hysteresis between discharge and several parameters of water quality, such as concentrations of suspended sediment (House and Warwick, 1998; Ide et al., 2009; Lefrançois et al., 2007; McDiffett et al., 1989; Nadal-Romero et al., 2008; Williams, 1989) and that of P (Bieroza and Heathwaite, 2015; Bowes et al., 2015; Ide et al., 2008; Lloyd et al., 2016; Ramos et al., 2015). The shape of the hysteresis depends on many complex factors that involve both chemical and hydrological processes (House and Warwick, 1998) and can be used as a tool to evaluate the transfer dynamics of sediments and solutes, such as P at a catchment level.

The hysteresis of suspended sediment concentration (SCC) and total P (TP) can be assessed by the approach described by Lawler et al. (2006). Clockwise pattern occurs when the rising limb of the hydrograph have higher concentration of SCC and/or TP. It indicates a rapid mobilization, transport and deposit of TP and/or SSC, that is the main source is nearby or in the river flume itself. Counterclockwise trajectories occur when the concentration of SCC and/or TP is greater during the recession limb of the hydrograph, indicating slower transfer, characterized by the presence of more distant source. The hysteresis of dissolved P (DP) can be assessed by the three-component approach described by Evans and Davies (1998). This method indicates the main source of dissolved P (pre-event water, surface runoff, and subsurface flow) based on rotation pattern, curvature and slope of hysteresis pattern.

There are only a few studies in Brazil that evaluate the intra-event pattern of solute transport (such as P) and its relationship with the dynamics of runoff and suspended sediment concentration. This study aims to describe the temporal pattern of the dynamics of P during significant rainfall events and to establish the relationships of the losses of P with the hydrological dynamics of the catchment, as well as with soil use and the management in a rural catchment with intensive soil use. This may be used as support to state and national agencies involved in the environmental legislation on water quality and the design of countermeasures.

2. Material and methods

2.1. Description of the catchment

The Arroio Lajeado Ferreira catchment is located in the municipality of Arvorezinha, which is in the north-central region of the state of Rio Grande do Sul (28°52′S and 52°05′W), southern Brazil (Fig. 1). With a drainage area of 1.23 km^2, it characterizes a catchment typical of the Taquari-Antas fluvial system, one of the main tributaries of the Jacuí