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Characteristics, lability and distribution of phosphorus in suspended sediment from a subtropical catchment under diverse anthropic pressure in Southern Brazil

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ABSTRACT

Measuring lability of anthropogenically enriched sediment-bound phosphorus (P) to water is a useful tool in ecological monitoring and planning mitigation to tackle diffuse P sources to surface waters. In current study, the sediment-associated total P, P fractions, and P lability accounting for river P legacy was determined. We monitored six representative headwater sub-catchments differing in land-use and management i.e., forest, recently turned low agriculture under conventional-tillage (CT), low agriculture under CT dominated with *Ilex paraguariensis* plantations, intense agriculture under CT, intense agriculture under no-tillage (NT), and highly anthropic urban receiving untreated sewage; and five sites on the main river in Guaporé river from October 2012 to October 2014. Total P and individual P fractions in 63-μm particle size were determined following the Hedley fractionation and the mean TP concentration lied between 752 mg kg^{-1} in forest to as high as 1738 mg kg^{-1} in highly anthropic sediments. The individual P fraction when pooled for different P lability indicated 10, 35, and 55% of TP as labile, moderately labile and non-labile P, respectively. With a land use shift from forest to highly anthropic urban, an increase in labile P (172%), moderately labile P (705%) and non-labile P (874%) was observed. The consistent higher values of non-labile ($Pi + Po_{HID-0.5}$) and residual P in urban, high agriculture and main river sediment indicates the high P affinity due to the presence of high Fe/Al oxides. Temporal analysis revealed that regardless of P lability, a higher concentration was found in winter months (July to November) particularly under CT sub-catchment showing high sediment production and increased transport of added P during tobacco cultivation period. The results provided a baseline to revisit the current fertilization and soil management practices to minimize the river P legacy for sustainable ecological management.

1. Introduction

While the developed countries are debating about the global P stewardship and its wise use for the well-being of the society and environment, the developing regions still need a great research to identify the potential P hot spots for suitable P management (Withers et al., 2015). The presence of P-rich suspended sediments (SS) is a significant risk to the fresh water and have raised serious concerns on the functional integrity of the whole lito-hydrosphere across the globe (Jarvie et al., 2006; Rowe et al., 2015). Therefore, increased understanding of the catchment scale interactions between the freshwater river system and P dynamics of headwater resources and/or rivers function as a corridor of the watershed to facilitate P delivery to lake or ocean via transportation is of great importance for ecological environment. It is a well-established fact that the excessive P inputs are driven by the over application of P fertilizers, manure, and untreated sewage wastewater often lead to the eutrophication (Withers and Jarvie, 2008; Sharpley et al., 2013). The adverse effects of eutrophication may range from a significant decline in the chemical and ecological quality of water bodies to whole human society and economy of a particular region (Withers et al., 2015).

Over the last three decades, in Southern Brazil, the anthropogenic modification of the landscape has been accelerated and

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the animal production has emerged as one of the most promising revenue generating sector in Brazilian agro-economy. Brazil is among the major competitor in international trade and export of agro-products like soybeans, poultry, swine, beef, corn and rice. As a result of expansion in poultry and dairy demands, the Brazilian livestock industry has expanded quickly to around 1741×10^6 animals (IBGE, 2010). The poultry industry alone with over 15 million MT poultry meat export is contributing approximately US$ 10 billion. Pig farming is practiced on relatively small farms (the area between 15 and 30 ha) but with the high slurry production $3600\,m^3\,yr^{-1}$ with hilly topography. These huge amounts of pig slurry have been applied to the soil successively on a small area without taking into account plant nutritional requirement and environmental concerns (Gatiboni et al., 2014; Couto et al., 2015). Therefore, the environmental hazards caused by this commercial activity primarily on water quality are much detrimental as result of their land application or either due to water consumption, with a eutrophication potential of 372 g TKN m^{-3} and a BOD_5 pollution load of 0.14–0.18 kg BOD_5 kg^{-1} per fowl (Kist and Moutaqi, 2009) in the region. The similar growth trend in cereal production and cattle population is predicted to 20 and 40% increase respectively by the year 2021–22 from the current number with an approximate addition of $4107 \times 10^3\,Mg\,P\,yr^{-1}$ to the environment (AGE, 2012; Tiecher et al., 2014). Resultantly, the consumption of agro-industrial P-containing compounds is expected to increase further due to dietary preferences both for human and animal feed along with increased inflow of untreated effluent and sewage into the environment (Qu and Kroeze, 2010).

In the south Brazilian agriculture is the adoption of the no-tillage system (NT) since the early 1980s (Bollinger et al., 2007; Merten et al., 2015). Due to increased soil erosion control, enhance water retention and improve soil health and currently there is about $30\,M\,ha^{-1}$ of farmland under NT in Brazil (FEBRAPD, 2012). The farming community being convinced and confident that NT characterized by minimal soil disturbance and profile mixing is the best to control soil and surface runoff losses, increase biological activity, high crop growth and yields than conventional tillage (Olson and Ebelhar, 2009; Lafond et al., 2011). Nevertheless, the farmers removed the terraces from their field and with an insufficient topsoil crop residues have resulted in accelerated water erosion even under NT (Pellegrini et al., 2010; Streck et al., 2008; Didoné et al., 2014; Minella et al., 2015; Tiecher et al., 2015). Additionally, recent studies on long-term NT and surface P fertilization experiments have shown the nutrient stratification particularly of P in the soil surface (0–5 cm) layer (Tiecher et al., 2012; Ferreira et al., 2013). Repeated application of P in the soil surface contribute to environmental contamination (Sharpley, 2003; Guardini et al., 2012). The high annual rainfall erosivity and sloping topography turned this area as P hot spot. There is high eutrophication risk of anthropogenically mobilized sediment associated P from Guaporé watersheds to enter into Jacqui river and ultimately reaches in the Guaíba lake, which is the only water source for 2 million metropolitan population of RS and Porto Alegre city, as well as a potential contaminant to the whole costal line of South Atlantic Ocean.

Conversely, recent studies carried on four soil types in A horizons occurring in Guaporé catchment has demonstrated the high content of crystallized iron i. e., hematite, goethite, goethite–ferrihydrite and gibbsite. Mostly adsorbed P was found associated with the goethite and clay content (Bortoluzzi et al., 2015; Fink et al., 2016). Therefore, the average P application is at higher rates when compared to other regions of the world due to compensate rapid immobilization of soil solution P by the presence of high secondary presence of high Fe and Al contents in these soils (Novais et al., 2007; Sattari et al., 2012). During soil saturated conditions and or the dry season in river, the reducing conditions accelerate the reduction of Fe(III) to the more soluble Fe(II) with subsequent release of the strongly fixed P. This phenomenon significantly enhances the soluble P fraction in soil and sediments and the soluble reactive P in the river water.

Several P sequential fractionation schemes have been developed to characterize lability of soil, sediment and manure P based on susceptibility to extraction (Tiessen and Moir, 1993; Condron and Newman, 2011). However, the simplest and fairly standardized scheme that separate different P fraction into various pools by lability i. e., labile-P (H_2O, resin, and 0.5 M $NaHCO_3$-Pi and Po), moderately labile-P (0.1 M NaOH-Pi and Po), and stable-P (HCl and residual) fractions are by Hedley et al. (1982). It is worldwide adopted and accepted for diverse type of land-use and management systems (Negassa and Leinweber, 2009; Hund et al., 2013).

There are many studies have been conducted on soil P fractionation to assess the P lability in response to tillage (Fink et al., 2016), cropping pattern (Tiecher et al., 2012), manure and fertilizer management (Rheinheimer and Anghinoni, 2001; Pavinato et al., 2010; Rodrigues et al., 2015) in the region. A few studies have also been focused on particulate and dissolved P characterization in runoff from the field and or small catchment scale (Pellegrini et al., 2010; Lourenzi et al., 2015). There is, though, a lack of research on the regional scale monitoring of suspended sediment P fractionation and pattern of P lability within such sediments and also to link this information to the land use and its implication for ecological P management.

This study was carried out in Guaporé catchment situated in the northeastern part of the Rio Grande do Sul state, the most Southern Brazil. The catchment with a basin area of 2000 km^2 was chosen to monitor and characterize the sediment-bound P behavior, sediment load and hydrological processes with representative land use, soil and landscape conditions, as well as the fact that it offers a wide heterogeneity at sub-catchment scale with varying anthropic and conservation agricultural practices. The catchment is located on the plateau slopes with steep hilly slopes and highly vulnerable to ecological fragility.

In this context, this study aims to provide a basis for understanding the characteristics and distribution of P compounds in suspended sediments of Guaporé catchment by Hedley P fractionation. We hypothesized that (i) the availability of a specific sediment P fraction extracted will vary in response to land use and anthropic activity, (ii) either P lability will differ or is exchangeable to some extent depending on sediment characteristics, and (iii) how temporal changes in sediment P fractions can explain changes in estimated river P legacy for better management and decision-making.

2. Materials and methods

2.1. Catchment geomorphic characteristics, agriculture and land use patterns

The study catchment covers part of the physiographic regions of the middle plateau (upper third of the basin) and the lower northeastern slope (intermediate and lower thirds of the basin). The Guaporé river is a tributary of river Taquari, and Taquari river is part of the regional hydrographic Guaíba estuary. The altitude of the basin varies widely, from 40 m near its confluence with the river Taquari to 800 m in the north at the starting part of the right portion of the basin (Fig. 1). The climate is classified as Cfa according to the Koppen climate classification. Mean annual rainfall varies between 1400 and 2000 mm with well distributed over the year, however, high rain occurs during winter months (August–October) and relatively less rainfall during summer (February–March). The mean annual temperature is 17.4 °C. Geology is diverse but predominated by volcanic lava flows and basalt with undulating to hilly type relief