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# Establishing a sediment budget for a small agricultural catchment in southern Brazil, to support the development of effective sediment management strategies

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SUMMARY

The rapid expansion of agriculture in Brazil has increased erosion rates and sediment yields, causing many negative environmental and economic impacts, both on- and off-site. However, to date, very few catchment-scale sediment budget investigations have been carried out in Brazil. Given the need to reduce the negative off-site impacts of increasing agricultural activity, there is an important need for such investigations in order to inform the development of effective sediment management strategies. Against this background, $^{137}$Cs measurements have been combined with measurements of sediment yield and fingerprinting the source of the fine sediment output, to establish a provisional sediment budget for a small (1.19 km$^2$) agricultural catchment in southern Brazil. The catchment is located in an area of steep highly erodible basaltic terrain, which has been intensively cultivated with tobacco. An ongoing monitoring programme provided information on the sediment yield from the catchment and existing suspended sediment source fingerprinting investigations provided information on the main sediment sources contributing to the sediment load at the catchment outlet. $^{137}$Cs measurements have been used to estimate medium-term erosion and deposition rates along 17 transects across the cultivated slopes and to quantify sedimentation rates within valley floor sediment sinks. These data have been used to estimate sediment redistribution rates within the cultivated areas of the study catchment and sediment accumulation in the valley floor sinks. The information provided by the three primary data sources has been integrated to establish the sediment budget for the catchment over the past 57 years. The individual terms of the budget necessarily involve much uncertainty, but its closure adds confidence to the final result. The budget calculations indicate that the study catchment has a sediment delivery ratio of ~15%. The implications of the key features of the budget for developing effective sediment management strategies are discussed.


## 1. Introduction

Most existing soil erosion studies undertaken in Brazil have involved investigations based on small plots (<77 m$^2$), using both natural and simulated rainfall (Merten and Minella, 2013). The aim of most of these investigations has been to parameterize the USLE (Wischmeier and Smith, 1978) for Brazilian conditions, or to assess the effect of specific management practices on rates of soil loss (e.g. Engel et al., 2009). Studies of erosion and sediment yield based on small and medium-sized agricultural catchments are rare in Brazil and associated catchment-scale data are therefore very limited and generally discontinuous (Merten et al., 2010). As the scale of attention moves from the plot to the catchment, the off-site or downstream impacts of soil erosion generally assume increasing importance. These impacts include reduction in stream and river water quality, due to the presence of fine sediment, downstream transfer of sediment-associated nutrients and contaminants, degradation of aquatic habitats and reservoir sedimentation (e.g. Becker et al., 2009; Kaiser et al., 2012; Tundisi et al., 2012; Didoné et al., 2014). In some situations, these off-site or downstream impacts may be more important than the on-site impacts which relate primarily to soil degradation and loss of productivity. In Brazil, the current lack of detailed understanding of the additional processes involved when changing scale from plot to catchment currently makes it difficult to upscale the information obtained from experimental plots to small and medium-sized

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catchments. Furthermore, lack of understanding of the interaction between land use and management and the mobilization, transfer and redistribution of sediment at the catchment scale may limit the effectiveness of sediment mitigation and control strategies.

In recent years, the international scientific community has devoted considerable effort to quantifying the off-site impacts of agricultural land use and the potential for reducing such impacts through sediment control and management programmes (e.g. Valentin et al., 2008; Nyssen et al., 2009; Shields, 2009; Simon et al., 2011). In this context, catchment sediment yield has been used as a key indicator of catchment response. However, the complexity of the processes linking the catchment surface to the stream network, and the scale effects noted above, introduce important problems when using measurements of sediment yield at a catchment outlet to deduce the erosion and sediment delivery dynamics operating within the upstream area (Porto et al., 2011; Jetten and de Vente, 2011). There is a need to couple such measurements with information on the internal functioning of the catchment and more particularly catchment-scale sediment mobilization, redistribution, transfer and storage.

Walling and Collins (2008) have emphasized how the catchment sediment budget provides a valuable concept and tool for characterizing the mobilization, transfer and storage of sediment within a catchment. However, whilst attractive as a concept and synthesizing tool, establishing a sediment budget can prove a difficult task due to the wide range of processes involved and their temporal and spatial variability. To the author's knowledge few, if any, such studies have been undertaken in Brazil. Most studies undertaken elsewhere that have attempted to establish a catchment sediment budget have involved the integration of several different techniques/methodologies that together provide the required information on sediment mobilization, redistribution, transport, and storage within a catchment (see Walling et al., 2001; Van Dijk and Bruijnzeel, 2005; Golosov et al., 2008; Ritchie et al., 2011; Gellis and Walling, 2011). The development of two groups of techniques must be seen as having greatly increased the potential for establishing meaningful catchment sediment budgets. The first is the use of fallout radionuclides, particularly caesium-137 ($^{137}$Cs), to document the mobilization and redistribution of soil and sediment across the surface of a catchment and the deposition of sediment within sediment sinks (see Zapata and Nguyen, 2010; Matisoff and Whiting, 2011; Walling, 2012). The second is the use of sediment source fingerprinting techniques to identify the primary suspended sediment sources in a catchment and to quantify their relative contributions to the sediment flux at the catchment outlet (see Walling, 2005, 2013). Integration of this information with more conventional measurements of sediment flux at the catchment outlet can provide an effective basis for establishing the sediment budget for a catchment (Walling et al., 2001, 2006).

The global pattern of $^{137}$Cs fallout means that $^{137}$Cs inventories and activities are low in many areas of South America, relative to those in most areas of the Northern hemisphere. However, exploratory applications of the technique in the region have demonstrated its viability (e.g. Bacchi et al., 2003; Schuller et al., 2004). The first successful attempt to apply the $^{137}$Cs technique in Brazil is probably that reported by Guimarães (1988) undertaken in the 1980s. This study used $^{137}$Cs measurements to document soil erosion rates on well weathered tropical soils with sandy texture, at a latitude close to 20° S. Andrello and Appoloni (2004) also reported encouraging results when using $^{137}$Cs to estimate rates of soil loss from more clayey subtropical soils in southern Brazil. Other studies reported by Bacchi et al. (2003, 2011) and Correchel et al. (2006) have further confirmed the validity of the approach. However, there have to date been few studies in South America that have attempted to use $^{137}$Cs measurements to provide information to assist in establishing a catchment sediment budget. Sediment source fingerprinting techniques have been successfully used in several catchment investigations in South America in recent years, for example by Minella et al. (2008), Schuller et al. (2013) and Franz et al. (2014). However, to the authors' knowledge such techniques have not to date been applied in South America for developing a catchment sediment budget.

The study reported in this contribution aims to explore the use of both $^{137}$Cs measurements and sediment source fingerprinting, along with measurements of sediment yield, to establish a sediment budget for a small rural agricultural catchment located in the steep basaltic terrain of southern Brazil. Sediment source fingerprinting investigations had already been undertaken in this catchment (Minella et al., 2008) and such data were therefore readily available. An understanding of the sediment budget of the catchment was seen as providing important support for the development of effective sediment management and control programmes in the local region.

## 2. The study catchment

The study focuses on the Arvorezinha experimental catchment (1.19 km$^2$) (Fig. 1), which was established in 2002 to provide a research and teaching platform aimed at exploring land use and management impacts on runoff generation, sediment yield and water quality. The catchment is located on the southern plateau of Brazil (28°49′30″W, 52°12′29″S). Following Köppen (1948), the climate is classified as subtropical super-humid mesothermic (Cfb). Based on local long-term precipitation records (daily totals), the mean annual rainfall for the periods extending from 1962 to 2011 and from 2002 to 2011 was ca. 1700 mm and 1800 mm, respectively (Fig. 2). Rainfall erosivity is approximately 6500 MJ mm ha$^{-1}$ h$^{-1}$ yr$^{-1}$, with 30% of this occurring during the months of September and October, when soil cover is generally minimal due to the local cropping practices. The catchment is underlain by acidic rhyodacite rocks and the highly erodible nature of these rocks has resulted in terrain characterized by steep slopes and deep narrow valleys. The soils are dominated by Acrisols, Cambisols and Leptosols according to the FAO system. The local topography is characterized by three distinct zones. In the lower third of the basin, the hillslopes are short and steep (150–300 m and 25–35% slope) and the valley bottoms are narrow (2–5 m). In contrast, in the upper third of the basin, the hillslopes are long (400–700 m), of intermediate steepness (7–15% slope) and the valley bottoms broader (10–15 m). In the middle third of the basin, the upper slopes are relatively gentle, but the slopes steepen further downslope towards the stream channels resulting in slopes with convex profiles. The valley bottoms are narrow and typically ca. 5–30 m in width. Due to the local geological conditions, the channel network is characterized by steep step-pool channels with high roughness and turbulent flow. The average channel gradient is 9% and the flow is strongly influenced by the presence of bed material with a diameter greater than 256 mm (pebbles and boulders).

Local agricultural activity is characterized by small farms (7–10 ha) producing tobacco, wood, and food crops. Soil tillage involves the use of oxen or small tractors. During the main monitoring period, which extended from 2002 to 2011, the dominant land use in the catchment, which exerted a strong control on soil erosion, was tobacco (covering over 90% of the area). Lopes (2006) analyzed old aerial photographs and conducted interviews with farmers, to reconstruct the evolution of land use in the catchment (Fig. 3). The spatial distribution of the current cropped areas (Fig. 4) must be seen as representative of the pattern that has existed since 1990, although some differences will exist, due primarily to the need for periodic fallowing of cropped fields, in order