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Water balance in paired watersheds with eucalyptus and degraded grassland in Pampa biome

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ABSTRACT

Rangelands of the Pampa biome, which cover regions of Argentina, Uruguay and Brazil (176,496 km^2 – 2.07% of Brazilian territory and 63% of Rio Grande do Sul State territory, southern region of Brazil) in South America (total area of 750,000 km^2), are being substituted by crops and commercial eucalyptus, with potential impacts on ecological and hydrological response of watersheds and river basins. We evaluated the influence of vegetation cover on hydrological processes by describing the water balance and its components (rainfall – P, interception, throughfall, actual evapotranspiration – ETa, groundwater recharge – G, and streamflow – Q) in two paired watersheds. One watershed being cropped to 7-year-old *Eucalyptus saligna* stands (forest watershed – FW; 0.83 km^2) and another consisted of degraded grassland with native and exotic grasslands (grassland watershed – GW; 1.10 km^2) used for livestock production in the Rio Grande do Sul State. The study was conducted from October 2012 to September 2014, during two hydrological years: a normal year from October 2012 to September 2013, and a wetter year from October 2013 to September 2014. Pluviometers were installed to study the partition of rain, along with watershed gauges and equipment for monitoring hydrological variables. Meteorological data (maximum and minimum temperature, relative humidity, wind speed, and solar radiation) used to calculate potential evapotranspiration were collected from a tower installed in the FW, whereas hydrological data (P and Q) were collected by sensors installed in each of the watershed spillways. During the normal year, P was 19% above the annual historical average for the region, which is 1314 mm, whereas in wetter year, rainfall was 98% above the same average. Total rainfall interception was similar between years in GW (9 and 10%), but different between years in FW that was higher in wetter (24%) then in normal year (16%). In the normal year, streamflow were 64% lower in the FW compared to the GW, while ETa and G were respectively 37% and 25% greater in the FW compared to the GW. In the wetter year, streamflow was 66% lower in the FW than in the GW, while ETa and G in soil were respectively 27% and 46% greater in the FW compared to the GW. Flow with 5% time streamflow (Q_5) was greater in the GW compared to FW in both normal and wetter years. Streamflow in the GW and FW were equal at Q_{80} and Q_{82} in the normal and in the wetter years, respectively, and exceedance probability curves crossed over at Q_{81} and Q_{82}, where the exceedance probability curves become greater in FW than in the GW. Even if the forest watershed had greater ETa compared to the grassland watershed, benefits such as greater interception and lesser surface runoff can be highlighted, for a condition where grassland was degraded and provided low aboveground biomass. Thus, the cultivation of eucalyptus stands may provide better structural conditions and ground cover, greater infiltration and soil water retention, and increased groundwater recharge, with consequent reduction

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of soil degradation by erosion and increased water availability during dry periods. Long-term use of forest systems, especially when compared to degraded grassland, may provide improvement on soil physical quality. However, these comparative results may not be valid for conditions during harvesting and tillage operations, neither when soil under grasslands has improved physico-hydraulic properties.

1. Introduction

The southern grasslands or Pampa biome consists of a total area of 750,000 km^2 in South America, and 176,496 km^2 of this area are located in the southernmost Brazilian state of Rio Grande do Sul – RS (2.07% of Brazilian territory). Rich in biodiversity, this biome covers most of the RS State territory (63%) and represents 90% of rangelands of the state (Roesch et al., 2009; Brasil, 2011, 2016). The Pampa biome is a mix of ecological formations intercalating in a single ecolandscape with intense flow of matter, energy and life among grasslands, riparian (gallery) forests, clumps of bushes, and forests on slopes (IBGE, 2004).

Eucalyptus plantations totaled 5.56 million ha of land in Brazil in 2014 (IBÁ, 2015), representing an increase of 11.9% (659,051 ha) compared to 2010 (IBÁ, 2014). In Rio Grande do Sul State, eucalyptus plantations was the main responsible for forest expansion areas, with a 67% increase in the last decade (AGEFLOR, 2016). The area of 184,000 ha covered with eucalyptus plantation in 2006 increased to the current 309,000 ha (35,958 more than in 2010) (IBÁ, 2014; AGEFLOR, 2016), covering areas previously used for agriculture and cattle breeding.

The increased demand for timber products is associated with the requirement of environmental protection, rational use of natural resources, and maintenance of ecological functions in biomes. Eucalyptus became the main species used in forest plantations for industrial purposes in Brazil (Silva et al., 2013; IBÁ, 2015).

The role of forests has been discussed concerning possible impacts on water resources conservation, particularly with regard to water consumption. Such discussions have reached significant dimensions through time (Jackson et al., 2005; Lima, 2006; Van Dijk and Keenan, 2007; Lima et al., 2012; Ferraz et al., 2013), where one of the most frequent criticisms relates to water consumption by eucalyptus and impacts on soil moisture, water in rivers and groundwater (Jackson et al., 2005).

Forest stands extract a larger amount of water by evapotranspiration. Furthermore, larger canopy interception compared to agricultural crops, and water consumption depends on land use (species, age and management), rainfall (amount and intensity), and other climate variables (Crockford and Richardson, 2000; Huber et al., 2008). Water consumption per annum[1] or per crop cycle[2] in millimeters is 1000–2000[1] for sugarcane, 800–1200[1] for eucalyptus, 800–1200[1] for coffee, 800–1200[1] for citrus, 400–800[2] for corn, and 300–600[2] for beans (Calder, 1992). These data show water consumption by eucalyptus is not very different from other perennial crops. Furthermore, Andréassian (2004) and Almeida (2012) state that water consumption per unit biomass produced by eucalyptus is not different from that of other species, whereas research on eucalyptus plantations in southeastern and southern regions of Brazil indicates that water use is not different from areas with native vegetation (Almeida and Soares, 2003; Carneiro et al., 2008).

Although water consumption is not very different among eucalyptus and other perennial crops, *Eucalyptus* spp. may influence the quality of shallow water tables in cultivated lands due to its ability to use groundwater (Cramer et al., 1999). The onset of groundwater consumption by plants can initiate a pathway of chemical inputs from aquifers to ecosystems, typically absent in groundwater recharge areas, as observed by Jobbágy and Jackson (2007) on soils in phreatophytic eucalypt plantations and native grasslands of the Pampas (Argentina), where slightly acidic waters in the grassland changed sharply within the eucalyptus plantation. Nonetheless, in regions with deep aquifers this should not be a major concern.

In regions where natural water supply is low, any unplanned change in the landscape, such as the replacement of forests with undergrowth, may result in increased water consumption and generate conflicts related to water use. Evidence from other regions suggests that forest plantation reduce water resources in small watersheds, but not in large ones (Van Dijk, 2007).

The most important hydrological flows affected by vegetation are interception of incident rainfall, infiltration, streamflow, and evapotranspiration, which in turn affect processes such as water storage in soil and water erosion (Chang, 2003). Depending on the density of vegetation cover, a proportion of rainfall is intercepted and temporarily retained by leaves and branches. For low rainfall intensity (<0.3 mm), the entire volume of rain is retained, whereas for more than 1 mm of rainfall only about 10–40% may be retained by canopy (Viessman Júnior et al., 1977).

Water balance allows studying watershed dynamics with environmental changes (Bosch and Hewlett, 1982; Bruijnzeel, 1990; Whitehead and Robinson, 1993; Arcova et al., 1998; Ranzini et al., 2004; Cicco et al., 2007) to assess water availability in watersheds and river basins. Thus, water balance provides important information for establishing strategies and measures for integrated resource protection and use.

Despite the advances on studies related to forestry, the role of natural and planted forests in the hydrological cycle is still superficially understood (Andréassian, 2004; Bruijnzeel, 2004; Kaimowitz, 2004; Oki and Kanae, 2006). For example, forest harvesting seems desirable in short term for streamflow in dry seasons, but may be a problem during rainy seasons when increased flow can risk flooding (Hamilton, 2008). In some cases, plantations may increase groundwater recharge by improving infiltration (Van Dijk and Keenan, 2007). Hydrological changes affect sustainable management, downstream conditions, soil yield potential, and watershed health, as well as generating conflicts over water use (Lima, 2005; Calder, 2007; Vanclay, 2009). However, studies evaluating the use of land with commercial forests indicate low sediment delivery rate (Rodrigues et al., 2014). Furthermore, rainfall interception and regulation of streamflow is greater (Baumhardt, 2010, 2014; Zuluaga, 2014; Lanza, 2015) and sediment yield is lower (Zuluaga, 2014; Rodrigues, 2015) in commercial forest areas compared to grassland areas.

We hypothesized that eucalyptus grown in the Pampa biome, in comparison to the natural grassland, significantly changes the components of water balance by decreasing streamflow, and increasing interception, soil deep drainage and soil water storage. We aimed to evaluate the influence of land use on soil water balance by describing the hydrological processes of rainfall, vegetation interception, evapotranspiration, deep drainage, soil water storage, and streamflow in two paired watersheds, one with eucalyptus plantations and