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The hydrologic consequences of land cover change in central Argentina

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ABSTRACT

Vegetation exerts a strong control on water balance and key hydrological variables like evapotranspiration, water yield or even the flooded area may result severely affected by vegetation changes. Particularly, transitions between tree- and herbaceous-dominated covers, which are taking place at increasing rates in South America, may have the greatest impact on the water balance. Based on Landsat imagery analysis, soil sampling and hydrological modeling, we evaluated vapor and liquid ecosystem water fluxes and soil moisture changes in temperate Argentina and provided a useful framework to assess potential hydrological impacts of vegetation cover changes. Two types of native vegetation (grasslands and forests) and three modified covers (eucalyptus plantations, single soybean crop and wheat/soybean rotation) were considered in the analysis. Despite contrasting structural differences, native forests and eucalyptus plantations displayed evapotranspiration values remarkably similar (~1100 mm y^{-1}) and significantly higher than herbaceous vegetation covers (~780, ~670 and ~800 mm y^{-1} for grasslands, soybean and wheat/soybean (*Triticum aestivum* L., *Glycine max* L.) system, respectively. In agreement with evapotranspiration estimates, soil profiles to a depth of 3 m were significantly drier in woody covers (0.31 $m^3\,m^{-3}$) compared to native grasslands (0.39 $m^3\,m^{-3}$), soybean (0.38 $m^3\,m^{-3}$) and wheat/soybean rotation (0.35 $m^3\,m^{-3}$). Liquid water fluxes (deep drainage + surface runoff) were at least doubled in herbaceous covers, as suggested by modeling (~170 mm y^{-1} and ~357 mm y^{-1}, for woody and herbaceous covers, respectively). Our analysis revealed the hydrological outcomes of different vegetation changes trajectories and provided valuable tools that will help to anticipate likely impacts, minimize uncertainties and provide a solid base for sustainable land use planning.

1. Introduction

Through their influence on water demand and supply, plants exert strong controls over many key hydrologic variables. In consequence, changes in land cover can affect the water balance and the quantity and quality of water resources. Aerodynamic roughness, albedo and leaf area seasonality are examples of key plant variables that affect water demand and shape evapotranspiration patterns, especially under relatively wet conditions (Calder, 1998). Under drier conditions, aspects of water supply, dictated in part by root extent, dominate over atmospheric water demand and help determine water use patterns by vegetation. The combination of deep root systems (Canadell et al., 1996), high aerodynamic roughness (Calder, 1998) and low albedo (Jackson et al., 2008) of forests usually allow them to maintain higher evapotranspiration rates and lower deep drainage fluxes in dry and wet conditions compared to herbaceous plants (Zhang et al., 2001).

The influence of vegetation on the partitioning of precipitation between wet (i.e., deep drainage and runoff) and dry (evapotranspiration) water fluxes controls water exchange with the atmosphere, streams, ground water, and the soil. Evapotranspiration, both as a component of the energy balance and a source of moisture to the atmosphere, may affect mesoscale circulation patterns and regional weather (Kelliher et al., 1993). Transpiration, the principal component of evapotranspiration over land, is tightly coupled with vegetation productivity in most ecosystems (Monteith, 1988). Deep drainage is the main water source that feeds groundwater bodies and, together with surface runoff, determines the water yields of watersheds. Changes in plant cover affecting the balance of liquid and vapor water can have a strong impact on ecosystem functioning, with important consequences on ecosystems services such as water, food, and hydroelectric power provision as well as hydrological and climatic regulation.

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The effects of changes in plant cover on hydrological processes have been studied globally using various approaches and different plant transitions. Transitions between tree- and herbaceous-dominated covers, which are taking place at increasing rates in South America (Paruelo et al., 2006), have shown the greatest impact on the water balance (Farley et al., 2005). For instance, native forest clearing for crop production in Australia and the Sahel has led to increased groundwater recharge and a raising of water-table levels because of the lower evapotranspiration rates of croplands (Schofield, 1992; Leblanc et al., 2008). In the opposite case, grassland afforestation usually increases evaporative water fluxes and reduces water yields (Farley et al., 2005; Nosetto et al., 2005). Transitions between structurally similar vegetation types, such as tree plantations from native forests or from grasslands to crops, have received much less attention, although the hydrological impacts could be large.

Tree plantations and crops are expanding rapidly in temperate South America, including Argentina, Uruguay and Paraguay. In Argentina, the area covered by annual crops increased at a rate of 0.27% per year between 1988 and 2002 (Paruelo et al., 2006), with 21 million hectares devoted to the production of rain-fed soybeans, wheat, maize, and other grains nowadays (MAGP, http://www.minagri.gob.ar/). Similarly, rates of land conversion to tree plantations, particularly fast-growing species such as eucalypts and pines, jumped from 23,000 to 125,000 ha per year during the 1992–2001 period (SAGPyA, 2002). The native grasslands of the Pampas and the native dry forests of the Espinal and Chaco districts have been the primary source of these expansions (Paruelo et al., 2006). Facing a rising global demand for food and fiber, a further expansion of croplands and afforestations seems likely. In addition to the direct economic benefits, the hydrological consequences of such vegetation changes should be considered for land-use planning, particularly in the context of an increasing frequency and intensity of extreme climatic events (drought and flooding) that could magnify vegetation change impacts (Viglizzo and Frank, 2006).

In this paper, we explore the hydrological effects of replacing native grasslands and native dry forests with crops, such as soybean and wheat/soybean systems, and eucalyptus plantations. We focus on the transition zone between the Pampas and the Espinal districts in temperate Argentina (Cabrera, 1976), where remaining patches of native grasslands and forest coexist with growing areas of grain crops and eucalypt plantations. We evaluated evapotranspiration patterns first for the 2000–2001 growing season in 60 plots of native grasslands, native forests, eucalyptus plantations, and annual crops, including soybean and wheat/soybean rotations, based on the thermal information provided by 13 Landsat images. We complemented these data with long-term estimates (11 years, 1994–2004) of water fluxes, including transpiration, soil evaporation and deep drainage, based on a water balance model (HYDRUS 1D, Šimůnek et al., 2005). Additionally, we characterized soil moisture profiles in detail at one location that encompassed adjacent stands of native grassland, dry forest, eucalyptus plantation, soybean and wheat/soybean system.

2. Materials and methods

2.1. Study region

We performed our study in the transition area between the Pampas and the Espinal districts in the Entre Ríos province (Argentina, Fig. 1). The study region lies between latitudes −32.11° and −31.69° and longitudes −60.57° and −60.06°. The area has a rolling landscape, with elevation that varies between 30 and 110 m a.s.l. The climate is humid temperate and the mean annual temperature is ∼18.5 °C. Mean temperatures for the coldest (July) and warmest (January) months are 12.4 °C and 25 °C, respectively. Mean annual rainfall is 1100 mm and it has a summer-dominant distribution, with 65% of which occurs during spring and summer (October–March). Mean annual potential evapotranspiration (Penman–Monteith) is 1150 mm and 71% of it occurs during spring and summer. The rolling landscape together with relatively high rainfall has led to a high density of rivers and streams in the area. Soils in the area developed from loessic materials and are dominated by Mollisols (∼85%) and Vertisols (12%) in a lesser extent. Among Mollisols, Acuic Argiudol is the dominant soil subgroup, followed by Vertic Argiudol but in much less proportion. These soils are well drained and have a silt–loam or silty–clay–loam texture in the surface layers. Clay content in the surface layer is usually between 25% and 30%. Iron and manganese mottles and calcium carbonate concretions may be found in the soil profile. Organic matter content varies between 2% and 4% in the surface layer (INTA, 1998).

Fig. 1. Location of the study region showing the original grassland distribution of the Pampas (light gray) and the original dry forests of the Espinal and Chaco districts (dark gray).

Since our study region is located in the transition zone between the grasslands of the Pampas and the dry forests of the Espinal district (Fig. 1), remaining patches of both covers could still be found in the area, but they are being converted to croplands at rapid rates (Paruelo et al., 2006). Although it is not very certain, the limit between both phytogeographical districts seems to be related with a climate switch towards a negative water balance during part of the year; conditions that favor the competitive ability of the grasses (Soriano et al., 1991). An alternative hypothesis suggests that a high fire frequency during the pre-Columbian time destroyed original scrubs and forests, promoting the prevalence of grasses in the Pampas (Soriano et al., 1991). C_3 and C_4 grasses of the genera *Paspalum*, *Axonopus*, *Stipa*, *Bromus*, and *Piptochaetium* dominate the grassland areas, while trees of the genera *Prosopis*, *Acacia*, *Jodina*, *Celtis*, *Schinus*, *Geoffroea* are the most common components of the dry forests. Currently, most of the study area is devoted to the rain-fed production of soybean (*Glycine max* L.), wheat (*Triticum aestivum* L.), maize (*Zea mays* L.) and sunflower (*Helianthus annus* L.). Average yields of soybean and wheat, the two dominant crops, are 2.5 and 3 tonnes ha^{-1} (SAGPyA), respectively. Eucalyptus plantations are not a dominant vegetation cover, but the afforested area in the whole province of Entre Ríos now approaches 90,000 ha and