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The influence of land-use changes on soil hydraulic properties: Implications for runoff generation

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Abstract

Many modern landscapes in the humid tropics appear as a mosaic of primary forest, agricultural land and abandoned areas at various stages of regrowth. Whereas the hydrological functioning of primary forest and agricultural ecosystems is known to some degree, the impact of secondary forests on the hydrological cycle has yet to receive the same attention; this is particularly true for the effects of forest regrowth on soil hydrology. We investigated the effects of land-use and land-cover types representative of largely deforested areas of the Amazon basin on soil hydrological flowpaths by quantifying infiltrability and field-saturated hydraulic conductivity (Ksat) at two depths (12.5 and 20 cm) under primary forest, recently cleared secondary forest (prepasture), teak (*Tectona grandis*), pasture and secondary forests originating from a former banana–cacao plantation (banana) and from pasture (capoeira). We further inferred potential changes in the hydrological flowpath regime by comparing our results with prevailing rainfall intensities.

Infiltrability varied ($\alpha = 0.05$) among the cover types according to: {forest} > {banana, capoeira, teak} > {pasture}, with prepasture overlapping with forest, banana and capoeira. Although the infiltrability of pasture is lower by an order of magnitude in comparison to the other cover types, this decrease does not affect flowpath patterns as infiltrability still exceeds even the highest short-term, such as 5 min, rainfall intensities. Ksat at the 12.5 cm depth varies as follows: {forest, banana, capoeira} > {teak} > {pasture}, with prepasture being undistinguishable from the first group. Under teak and pasture, Ksat is lower than prevailing rainfall intensities, which implies the possible generation of a perched water table at a shallow depth and hence the generation of saturation overland flow. The impact of 13 years of cattle grazing prior to planting teak is still measurable even after 10 years of growth. At the 20 cm depth, the differences in Ksat among the land uses are minor compared to prevailing rainfall intensities, i.e., the vertical flow of water is impeded regardless of land use.

We conclude that there is a considerable memory effect; hence, any assessment of the hydrological functioning of secondary forests, quasi-natural or man-made, must take into account the kind, intensity and duration of land use prior to regrowth.

Keywords: Land-cover change; Secondary forest; Infiltrability; Saturated hydraulic conductivity; Runoff generation; Deforestation; Pasture

1. Introduction

The clearing of primary rainforest continues to occupy centre-stage of the global preoccupation with tropical environmental issues (e.g., The Economist, July 24, 2004), as it has over several decades. This exclusive view of land-cover change in tropical rainforest areas tends to imply irreversibility, and hence to overlook the actual, rather more diverse pattern of such changes. In Brazil, for instance, the predominant land cover after forest conversion is pasture (Serrão and Toledo, 1990). But this is rarely the final state: according to Serrão and Homma (1993), half of the pasture area in the Brazilian Amazon was degraded by the early 1990s. Moreover, agricultural land often goes to fallow, that is, land users let it "rest" for the recovery of soil fertility (Nicholaides et al., 1984; Sanchez, 1994). Secondary vegetation will eventually reclaim such lands. In 1992, for example, 210 municipalities of the Brazilian Amazon had over 7% secondary forests cover (Perz and Skole, 2003b). For the frontier subregion, the focus of regional development policies since the 1970s (Perz and Skole, 2003b), which mainly includes the Brazilian states of Rondônia, Mato Grosso and Pará, the following land-cover distribution is estimated by the Basic Science and Remote Sensing Initiative (BSRSI, 2001) for 1992: primary forest

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85.5%, deforested land 11.9% and secondary forest 3.9%. Approximately 33% of the land is claimed in rural establishments. Respondents in agricultural censuses in 1996 categorized 51.8% of this land as natural forest and 30.9% as pasture (Perz and Skole, 2003a). The remaining area is partitioned into unproductive land, which often consists of degraded land with successional vegetation (6.5%), ''managed regrowth'' (fallows, perennials and forest plantations; 3.0%) and annual crops and natural pasture (7.8%).

Recently, these ''new'' land covers and ''new forests'' (Lugo and Helmer, 2004) have begun to attract considerable interest: how do their properties and functioning differ from that of native forest? One aspect in which they might differ is their hydrological functioning. The soil hydrological effects of land clearing and subsequent land use in the humid tropics have been studied in some detail (e.g., Ghuman et al., 1991; Alegre and Cassel, 1996; Arevalo et al., 1998; Gijsman and Thomas, 1996; Horowitz et al., 1999; Bonell and Molicova, 2003; Martinez and Zinck, 2004), whereas the hydrological response to secondary growth is virtually unknown (an exception is Ziegler et al., 2004); the same argument applies to plantation forests (Bruijnzeel, 2004).

Our investigation focuses on infiltrability and saturated hydraulic conductivity because these variables are particularly sensitive to soil disturbance (Schoenholtz et al., 2000; Alegre and Cassel, 1996), and can therefore serve as indicators for the influence of land use on the soil. Our objectives were: (1) to quantify this influence by field estimation of infiltrability and saturated hydraulic conductivity (hereafter 'Ksat') under different land covers in Rondônia, Brazil, and (2) to interpret this influence in the framework of near-surface hydrology.

2. Research site

All field measurements were conducted at Rancho Grande (10°18′S, 62°52′W, 143 m a.s.l.) in the northwestern Brazilian state of Rondônia (Fig. 1). The mean annual temperature is about 27 °C, and the mean annual precipitation is 2300 mm (Schmitz: land owners since 1980, personal communication) with a marked dry period from June to September.

The area belongs to a morphostructural unit known as ''Southern Amazon Dissected Highlands'' (Planalto Dissecado Sul da Amazônia, Peixoto de Melo et al., 1978), which is characterized by a very pronounced topography with an altitudinal differential of up to 150 m: remnant ridges of Precambrian basement rock, made up of granites and gneisses of the Complexo Xingu (Leal et al., 1978), are separated by flat valley floors of varying width. Soil orders associated with this morphostructural unit are as follows: (1) Ultisols, Oxisols and Inceptisols (Soil Survey Staff, 1999) on steep slopes and (2) Entisols (Soil Survey Staff, 1999) along streams.

Based on soil textural changes with depth and cation exchange capacity in the diagnostic horizon, we classified the soils on our plots as Kandiudults (Soil Survey Staff, 1999).

The primary vegetation is open rain forest with a large number of palm trees. It covers all hills and portions of the lowland. The remaining area was cleared between 1979 and 1980, mainly by slash and burn, although big logs were removed by bulldozers. The cleared area was converted to pasture, a portion of which was later planted to teak (*Tectona grandis*), and to a banana–cacao plantation, which was subsequently abandoned; 75 ha of the originally cleared land reverted to secondary forest. This kind of farm-scale land-use pattern reflects the mosaic typical for many parts of Rondônia.

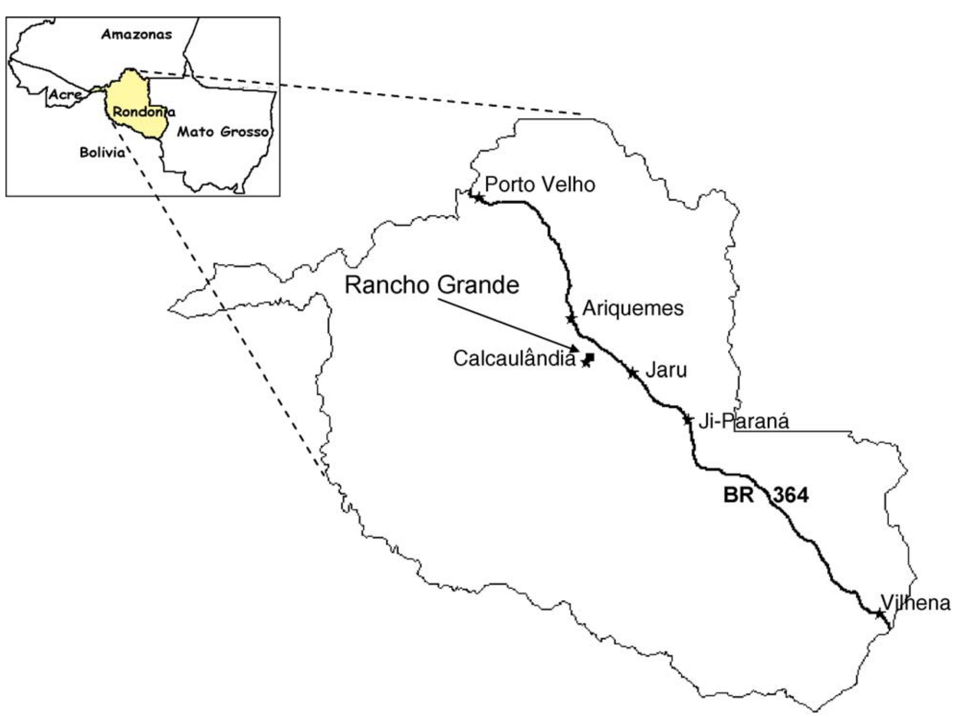

Fig. 1. Location of the research site.