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Short communication

Slash-and-burn agriculture: Establishing scenarios of runoff and soil loss for a five-year cycle

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ABSTRACT

Shifting cultivation is an age-old agricultural system that coexists with modern agricultural systems, particularly in the tropics. The characteristics and effects of shifting cultivation are well documented in the literature, including: soil degradation and erosion, nutrient depletion, impacts on biodiversity, and economic trends. Although studies report soil loss during the cropping period under shifting cultivation, few studies have assessed soil erosion during a full slash-and-burn cycle. The objectives of this study were to characterize runoff and soil loss for a full 5-year regeneration cycle in a slash-and-burn system. The measurement of runoff and soil loss was based on three replicate 2-m^2 plots installed in each monitored area. Three agricultural plots in different stages of regeneration were monitored. The data were analyzed by month and year for the 5-year regeneration cycle. Runoff and soil loss decreased exponentially from the burned phase to the early stage of secondary forest. Runoff and soil loss exhibited patterns similar to those of a forested area after only 4–5 years of regeneration. In general, areas undergoing slash and burn in the Guarapuava region are stable and the fallow length, as well.

1. Introduction

The history of land occupation in the middle of South Parana is strongly related to the exploitation of natural resources. Today, agriculture is an important economic activity in the Guarapuava-Parana-Brazil region, and is characterized by two main types of systems. The first is modern commercial agriculture that uses advanced technologies in soybean, corn, oat, and barley production. The second is subsistence agriculture, which produces primarily corn and beans, and occupies less productive soils located on steep slopes that border escarpments and well-dissected valleys (Thomaz, 2009).

Despite the emergence of modern agricultural systems (e.g., no till), the slash-and-burn system persists in many parts of the world, particularly in the tropics (Grau and Diego Brown, 2000; Borggaard *et al.*, 2003; Mertz *et al.*, 2009; Thomaz, 2009; Ziegler *et al.*, 2009; Grogan *et al.*, 2012; van Vliet *et al.*, 2012). Many researchers believe that the slash-and-burn system would not be sustainable in the long term if the duration of the fallow period were to be reduced (Devendra and Thomas, 2002; Borggaard *et al.*, 2003; Styger *et al.*, 2007). Reducing the length of the fallow period has several consequences for areas that have been slashed and burned, including increased soil degradation and erosion, a decrease in aggregate stability, and depletion of soil nutrients (Ziegler *et al.*, 2009). Soil degradation takes place because insufficient time is allowed for vegetation and soil structure to develop and for stocks of carbon and nutrients to be replenished. As a consequence of yield reduction, more areas are incorporated into agricultural production to maintain the required harvest levels.

Land rotations take place within the boundaries of private property, because there is no vacant collective land. The farmers are the owners, and plan the rotation system to ensure cultivable land is available each year. The land rotation lasts from 3 to 5 years. Slashing is performed mainly in the winter (June, July, and August) and burning is conducted in early spring (September and October). Slashed vegetation is spread over the ground, and 1–2 months are needed to dry the vegetation prior to burning (Thomaz, 2009).

A rotation cycle occurs over a period of varying intervals (3–5 years, 8–10 years, or >10–15 years). After slash and burn, vegetation is cropped for 1–2 years (Borggaard *et al.*, 2003; Denich *et al.*, 2005; Styger *et al.*, 2007). The rotation cycle practiced in the Guarapuava region occurs over a 3- to 5-year interval, and is characterized by different land-use phases. The phases of a full cycle of land use, in order, are as follows: clearing, burning, growing, abandonment, and recovery (Thomaz, 2009).

Several studies have reported soil loss during the cropping period but describe negligible or reduced soil loss during the fallow period (Ziegler *et al.*, 2009). In the Guarapuava region, the time

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Fig. 1. Study site and overview of the slash-and-burn process. (A) In the foreground, spread cut bushes drying on the ground, and in the background, shrub area after 3 years of regeneration. (B) Farmers managing the land using fire. (C) Area being burned. (D) Measurement plot installed after burning. (E) Measurement plot installed at fallow area in regeneration for 4–8 years after maize harvest.

period from burning to corn harvest is approximately 6 months. The fallow period begins immediately after the corn harvest, and can last up to 4 years in a regeneration cycle of 5 years. Because of the long duration of the slash-and-burn cycle, few studies are carried out to assess soil erosion over a full cycle (i.e., medium-term erosion). Despite the importance of slash and burn in Latin and Central America, compared to other tropical regions, there is a scarcity of case studies from these areas. In addition, most studies relate to the tropical forest frontier rather than in well-established agricultural regions (van Vliet *et al.*, 2012).

The objectives of this study were to (1) assess runoff and soil loss from areas of shifting cultivation over a 3-year period; (2) characterize runoff and soil loss patterns over a full 5-year cycle; and (3) discuss the soil loss tolerance limit for a 5-year regeneration cycle and the sustainability of slash-and-burn practices in the Guarapuava region.

2. Materials and method

2.1. Study area characteristics

The experiment was conducted in Guarapuava, Brazil (1073 m AMSL, 25°24′27″S, 51°24′53″W). The Guarapuava region has a wet, subtropical climate with mean annual precipitation of 1915 mm (based on measurements from 1976 to 2008), and mean annual temperature of 17 °C. The precipitation is distributed throughout the year (Instituto Agronômico do Paraná, 2008).

The measured slope formed by contiguous land in the study area is 32° (62%). The soil consists of Regosols (FAO classifications) formed from basalt rock with surface stoniness of 10–20%, and an approximate texture size distribution of 36% sand, 20% silt, and 44% clay. Soils are characterized by a slightly acidic pH (pH 5.8), low aluminum saturation (0.0%), and a carbon content of 56.5 g/dm^3.

2.2. Experimental design and establishment of soil loss and runoff monitoring

Experimental measurements took place between May 2003 and April 2006. Shrub growth was in the third year of regeneration at the onset of monitoring; at the end of the experiment the shrub area had undergone 5 years of regeneration. Other areas (burned, and fallow post-maize harvest) were in the early stages of regeneration (1–3 years); hence, it was possible to examine runoff and soil loss patterns during a 5-year regeneration cycle of shifting cultivation (Fig. 1).

The measurement of runoff and soil loss was based on 2-m^2 plots. This approach is applied to preliminary investigations of runoff and erosion in order to compare different land use systems (Hudson, 1993). Three replicate 2-m^2 plots were installed at random locations in each monitored area (shrub land, burned, fallow post maize harvest) (Fig. 1). Rainfall measurements were made using a rain gauge installed close to the experimental site. Precipitation was monitored daily, including the total accumulated rainfall. The procedures for collection and quantification of runoff and sediment are explained elsewhere (Hudson, 1993; Thomaz, 2009). The mean values of runoff and soil loss were compared using analysis of variance (ANOVA), and differences between individual means were tested with Tukey's test at $P < 0.05$.

3. Results and discussion

3.1. Precipitation regime and burn severity of slash-and-burn cycle

Rainfall was distributed throughout the monitoring period. The average annual rainfall recorded during the period of investigation was 18.7% lower than the historical average for the region. August registered the lowest rainfall. Rainfall was higher in spring, during the period of burning and sowing (Table 1).

Parameters observed in the field through visual assessment indicated that the intensity and severity of fire was low in the slash-and-burn experimental area (Fig. 2). During burning, the maximum height of flames was <4 m. After burning, topsoil was covered by a dark layer of partially burned material (e.g., litter, leaves, branches, twigs, stems, and grass tussocks). Ulery and Graham (1993) defined a fire of low intensity as having a temperature between 100 and 250 °C. In addition, fires of low severity and short exposure time have only a temporary effect on soil biological and chemical properties (Ketterings and Bigham, 2000). Fire severity has been characterized by maximum flame height, where a flame