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Short communication

Dynamics of aggregate stability in slash-and-burn system: Relaxation time, decay, and resilience

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ABSTRACT

Slash-and-burn is a traditional agroforestry system performed in tropical regions worldwide. Fire is the main tool in the slash-and-burn soil management. Most of the immediate and direct effects caused by fire are associated with changes on aggregate stability. However, there is a knowledge gap on the long-term effects of fire on soil aggregate stability resilience. In the present study, long-term monitoring (21 months) was carried out to assess the post-fire effects on aggregate stability. Aggregate stability is temporally dependent on each post-fire phase occurring in the slash-and-burn agricultural system. In this study, different phases that affect aggregate stability post-fire, including relaxation time, decay, and resilience, were suggested.

1. Introduction

The slash-and-burn agroforestry system still persists in tropical regions worldwide (Adams et al., 2012; van Vliet at al., 2012; Schmook et al., 2013; Bhagawati et al., 2015; Mukul and Herbohn, 2016). Positive aspects of the slash-and-burn agriculture include carbon stock maintenance (Bruun et al., 2009), increase in biodiversity (Padoch and Pinedo-Vasquez, 2010), low intensification of land use in comparison to conventional agriculture, and low energy input in food production (Ziegler et al., 2011). However, there are several negative aspects of this technique, such as tropical forest deforestation, soil erosion, carbon emissions, and biodiversity loss (Aragao and Shimabukuro, 2010; Borggaard et al., 2003; Gafur et al., 2003; Styger et al., 2007). Furthermore, the slash-and-burn system is a barrier to agriculture modernization and to poverty alleviation. In addition, soil management (Grogan et al., 2012) and alternatives to swidden agriculture to improve farmers' livelihood (Nath et al., 2015).

Fire is the main tool in the slash-and-burn land clearing. However, the severity of fire can indirectly affect the ecosystem responses, such as soil erosion and vegetation recovery (Keeley, 2009). In addition, fire causes immediate and direct effects on soil properties, such as carbon depletion, soil microbial population change, water repellency, and soil mineral alteration (DeBano at al., 1998; García-Oliva et al., 1999; Certini, 2005). Long-term fire recurrence affects the quantity and quality of soil organic carbon and decreases soil fertility. Moreover, fire recurrence can cause ecosystem functionality change (Mayor et al., 2016).

Most of the direct and indirect effects caused by fire are associated with aggregate stability (AS), such as carbon depletion (Mataix-Solera et al., 2011), soil water repellency (Fox et al., 2007; Mataix-Solera and Doerr, 2004), soil aggregate hardening (Thomaz, 2017b), and soil erodibility (Mataix-Solera et al., 2011; Shakesby and Doerr, 2006).

AS is a measure of the resistance of aggregates to internal and external disruptive forces (e.g., slaking, raindrop impact, and swelling). Therefore, AS is a soil property that indicates soil quality. It is associated with several processes, such as soil crusting, soil erodibility, soil water infiltration, soil water retention, and organic matter protection. In addition, disruptive methods are extensively applied to assess the aggregate stability (Kemper and Rosenau, 1986; Bissonnais, 1996; Hillel, 1998; Amézketa, 1999; Dıaz-Zorita et al., 2002).

Further studies on post-fire environmental dynamics in the slash-and-burn agroforestry system are necessary. In addition, information on slash-and-burn soil physics is very scarce (Mukul and Herbohn, 2016), although the immediate effects of fire on soil properties have been reported in slash-and-burn areas (Are et al., 2009; Thomaz, 2017a). However, there is still a knowledge gap on the effects of fire on long-term soil aggregate stability, especially in slash-and-burn systems. The main goal of this paper is to assess the long-term post-fire effects on soil AS and resilience under slash-and-burn system. Many studies show the immediate effect of fire on AS, but not on its long-term post-fire dynamics (Are et al., 2009; Mataix-Solera et al., 2011; Thomaz, 2017a; Thomaz and Fachin, 2014). This knowledge is of utmost importance for understanding the agroforestry system recovery and sustainability. Here, I have specifically focused on the recovery of the soils.

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2. Material and methods

2.1. Study area

The study was carried out in the Tijuco Preto rural community in Prudentópolis municipality, southern Brazil (25°23′46.6″ S, 51°6′21.7″ W). An area of approximately 0.25 ha was set on fire according to the local traditional slash-and-burn agricultural system. A typical plot used for shifting cultivation of maize and black beans was chosen for the long-term assessment of soil aggregate stability. Maize and beans are grown from spring and summer to early autumn (i.e., September to February–March). Slash-and-burn, as practiced in the study area, uses minimal technology (e.g., no-plow); only manual labor, and hoes are used throughout the cultivation period. No extra inputs are provided during cropping such as fertilizers and pesticides. The phases of a full cycle of land use, in order, are as follows: clearing, burning, growing, abandonment, and recovery. The fallow period generally lasts 5 years and the slash-and-burn system is practiced in the secondary forest.

Overall, after the slash-and-burn process and corn-bean harvest are completed, the land is covered by herbaceous, annual plant species. Primary plant species are buva amarela (*Solidago chilensis* Meyen), voadeira (*Conyza bonariensis* L. Cronq.) and vassoura-mole (*Senecio brasiliensis* Less). Other tussock species emerge, predominantly rabo-de-burro (*Andropogon* sp), capim barba-de-bode (*Aristida pallens*), caraguatá (*Eryngium* spp), capim caninha (*Andropogon icanus*), capim flexa (*Trystachia chrysothrix*), and caraguatá (Erydium spp). In the following 2–3 years shrub species dominate the area, in particular, vassourinha (*Miconia candolennas, Baccharis dracunculifolia* and *Baccharis* sp), and other secondary species including samambaias (*Pteridium aquilinum*), taquaras (*Merostachys* spp), and e arranha-gato (*Acacia plumosa*). After 3–4 years, native forest species begin to regrow or stand out, such as Bracatinga (*Mimosa scabrella*), canela-amarela (*Nectandra lanceolata*), canela-preta (*Nectandra megapotamica*), guabirobeira (*Campomanesia xanthocarpa*), erva-mate (*Ilex paraguariensis*), canela-lageana (*Ocotea pulchella*), pimenteira (*Capsicodendron dinisii*), capororoca (*Rapanea ferruginea*), guaçatonga (*Casearia sylvestris*), farinha seca (*Albizia niopoides*), açoita cavalo (*Luehea divaricate*), miguel pintado (*Matayba elaegnoides*), and timbó (*Ateleia glazioviana*) (Thomaz, 2013, 2016). The currently study cover the early post-fire regeneration stage (0–2 years).

The geomorphological characteristics of the burned plot are convex hill slopes, with a gradient of 11°. The average altitude is 820 m above mean sea level and the soil type is cambisol (Table 1). The climate is mesothermal, subtropical wet (type Cfb), with mean temperature below 18 °C in the coldest month July (mesothermal), and below 22 °C in the warmest month (January), without a dry season. Mean annual rainfall is 1600–1800 mm, annual evapotranspiration is 900–1000 mm, and mean annual temperature is 16–18 °C (Caviglione et al., 2000). The study area is in the subtropical morphoclimatic zone of the Brazilian southern highlands, which is cover by Atlantic pine forest (*Araucaria angustifolia*).

Table 1
Soil characteristics.

Soil type: Cambisols (FAO, 2006)	Sand ($g\,kg^{-1}$)	Silt ($g\,kg^{-1}$)	Clay ($g\,kg^{-1}$)
Soil depth (0-5 cm)	240	290	470
Soil organic matter (Walkley-Black) ($g\,kg^{-1}$)	50.7		
pH ($CaCl_2$ 0.01 M)	4.7		
CEC ($cmol\,kg^{-1}$)	16.0		
[a]Al_2O_3 ($g\,kg^{-1}$)	88.6 ± 7.2		
[a]Fe_2O_3 ($g\,kg^{-1}$)	32.7 ± 2.3		

[a] Source (Melquiades and Thomaz, 2016).

2.2. Water aggregate stability

Six soil samples were collected randomly for each assessed month randomly at the burned plots (6 samples per plot × 8 plots = 48 samples in total). The disturbed soil samples were collected with a metal ring (100 cm^3) at depths of 0–5 cm. In the laboratory 30 g of the sampled soil that had been sieved through a 16-mm mesh were subjected to the wet sieving disruptive method (Yoder, 1936). The samples were fractionated with sieves having the following sieve sizes: 8.0, 4.0, 2.0, 1.0, 0.5, and 0.25 (macroaggregate), and < 0.25 mm (microaggregate). The material was immersed in water for 5 min to allow capillary wetting, and agitated gently with upward and downward movements for 10 min (40 rpm). Thereafter, the material retained on each sieve was removed and dried at 105 °C for 24 h, followed by weighing of the fraction remaining on each sieve. In addition, the quantity of aggregates size in percentage was measured using the ratio between the aggregate amounts retained in the sieves with different mesh sizes to the total amount of sample (Amézketa, 1999; Bissonnais, 1996; Haynes and Swift, 1990).

The aggregate stability index (AS) (Eq. (1)) was assessed at 0 (pre-fire condition), 1, 3, 6, 9, 12, 15, and 21 months post-fire.

The AS index can vary from 1 to 100%, indicating the aggregation per soil treatment (Hillel, 1998; Castro Filho et al., 2002). The sand fraction was removed from the aggregate samples by a 0.053-mm sieve. The evaluation of aggregate stability at six months was performed only on three samples, at nine months on five samples, and at 21 months on four samples due to excess sand content. Soil organic matter (OM) content was determined by the Walkley-Black (1934) method in triplicate soil samples for each assessed month (3 replicate × 8 measurement = 24 samples in total).

$$AS\% = \frac{WA - WI - S}{W - S} \times 100 \tag{1}$$

$AS\%$ = Water aggregate stability in percentage
WA = Weight of the aggregates > 0.25 mm
WI = Weight of the aggregates < 0.25 mm
W = Weight of the sample
S = Sand

2.3. Data analysis

Analysis of variance (ANOVA) of the soil aggregate stability was performed to compare changes along the monitoring phases: relaxation, decay, and resilience. Differences between individual averages were tested using the post-hoc t-test. Homoscedasticity and normality (Shapiro-Wilk) of the samples were checked. Additionally, a simple correlation analysis (Pearson's correlation) was performed to evaluate the response of the organic matter content following the monitoring period.

3. Results and discussion

3.1. Long-term aggregate stability pattern and controlling factors

Soil aggregate stability was higher following the first post-fire month (Fig. 1a) and then decreased gradually between three and 12 months post-fire. Moreover, the aggregate stability reduction during this phase, ranged from 11% to 36% in comparison with the first month post-fire. After 15 months post-fire, the aggregate stability returned to the initial conditions. During the first three months, the aggregate stability was 91.2 ± 4.7% (n = 12). However, at 3–12 months after the fire, the aggregate stability decreased to 70.7 ± 15.6% (n = 20). Therefore, in the middle of the measurement, the aggregate stability decreased by 29% ($p < 0.001$). Finally, at the end of the monitoring (15–21 months post-fire), the aggregate stability increased to 88.8 ± 7.1% (n = 10). This value is similar to that of the initial