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Effects of ashes from a Brazilian savanna wildfire on water, soil and biota: An ecotoxicological approach

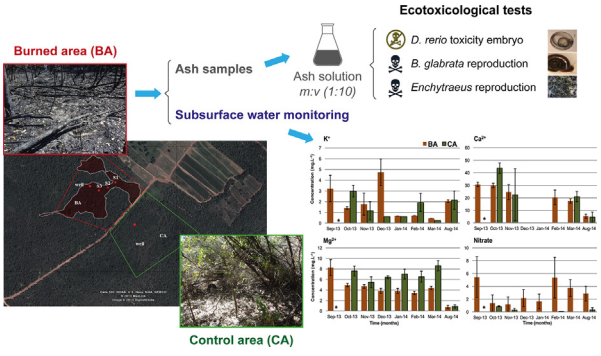
Eduardo C. Oliveira-Filho [a,d,*], Darlan Q. Brito [b], Zelia M.B. Dias [b], Mayara S. Guarieiro [d], Esther L. Carvalho [c], Maria L. Fascineli [c], Cintia C. Niva [a], Cesar K. Grisolia [c]

[a] Embrapa Cerrados (Empresa Brasileira de Pesquisa Agropecuária), Road BR-020, km 18, Planaltina, Federal District (DF) 73310-970, Brazil
[b] University of Brasília, Faculty UnB at Planaltina (FUP) Planaltina, Federal District (DF) 73345-010, Brazil
[c] Universidade de Brasília, Institute of Biology, Brasília, Federal District (DF) 70910-900, Brazil
[d] Centro Universitário de Brasília (UniCEUB) SEPN 707/907, Campus do UniCEUB, Asa Norte, Brasília, (DF), 70790-075, Brazil

HIGHLIGHTS

- We examined the effects of ashes on surface soil and subsurface water in a typical Brazilian savanna for one year
- Data showed high levels of exchangeable cations and OM content in soil, but it did not affect the soil pH.
- Effects of ashes on soil and subsurface water did not persist for one-year post-fire except for OM content in burned areas.
- No significant effects were observed for *D. rerio* embryos, but it was verified on reproduction of snails and enchytraeids.
- Bioassays in mesocosms are encouraged to understand the complexity of fire on soil and aquatic biota.

GRAPHICAL ABSTRACT



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ABSTRACT

Wildfire is very common in Brazilian savannas, and its effects on water, soil and aquatic/soil organisms are poorly understood. In this study, we observed the effects of fire, especially of ashes, on surface soil and subsurface water in a typical Brazilian savanna (*Cerrado* sensu *strictu*) for one year. Soil analyses (pH, organic matter content, potential acidity, K, Ca, Mg and P) and subsurface water analyses (NO^{3-}, PO_4^{3-} Mg^{2+}, Ca^{2+} and K^{+}) were assessed. We evaluated the ecotoxicological effects of ashes on three different endpoints and species, in fish *Danio rerio* (embryonic development), aquatic snail *Biomphalaria glabrata* (reproduction) and a soil species *Enchytraeus sp.* (reproduction). We found a higher amount of exchangeable cations and organic matter content in short-term fire effects on soil, but the higher availability of nutrients did not affect the soil pH in field plots. The effects of ashes on soil and subsurface water did not persist for one-year post-fire, except for organic matter content in burned areas. No toxic effects were observed on hatching success and incidences of developmental abnormalities in *D. rerio* embryos. However, ash input had adverse effects on reproduction in snails and enchytraeids. We reported a statistically significant decrease in snail eggs exposed to the 50 $g.L^{-1}$ and 100 $g.L^{-1}$ of ashes after four weeks ($p < 0.05$, Dunnett's test and Tukey test). *Enchytraeus* sp. reproduction was negatively influenced by the natural soil, which presents high acidity, and also when exposed directly to the ashes from burned area, suggesting that pH and other ash compounds may limit the growth of enchytraeids. More studies in burned areas are

* Corresponding author at: Embrapa Cerrados (Laboratory of Ecotoxicology), 73310-970 Planaltina, Distrito Federal, Brazil.
E-mail address: eduardo.cyrino@embrapa.br (E.C. Oliveira-Filho).

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strongly encouraged, addressing the potential important routes of exposure to ashes in order to understand the impact of intense fires on soil and aquatic biota in tropical savannas.

1. Introduction

Wildfires worldwide are events that feed major concern among scientific communities, governments and environmental managers, given their meaningful contribution to ecological roles (Durigan and Ratter, 2016) and disturbances in different environmental matrices (Lavorel et al., 2007; Shakesby, 2011).

Although the native flora benefits from fire events in some situations through adaptive strategies (Medeiros and Miranda, 2005; Marinho and Miranda, 2013), wildfires may cause adverse effects on the ecosystem, depending on their frequency, severity and intensity (Setterfield et al., 2010). A high incidence of wildfires, mainly caused by human activities, has been linked to the low recruitment of woody species and grass-dominated landscapes, biodiversity loss, erosion and impoverishment of soil (Silva et al., 1996; Miranda and Sato, 2005; Medeiros and Miranda, 2005; Mueller-Dumbois and Goldammer, 1990). Total fire suppression, on the other hand, replaces grasslands and savannas with forest vegetation, involving biodiversity losses (Durigan and Ratter, 2016).

The South American savanna, the *Cerrado* biome, covers 20% of Brazil's territory, mostly on the central plateau. The most abundant soil type is the dystrophic Red Latosol (Acrustox soil according to American classification), which is poor in a number of nutrients, including nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), sulphuri (S) and micronutrients (Haridasan, 1992; Lilienfein et al., 2001). The main physiognomic aspect is the coexistence of a woody (trees and shrubs) and a creeping layer (grasses and subshrubs) (Ribeiro and Walter, 2008). *Cerrado*, like other savannas, has rainy and dry seasons, in which the grass biomass dies and favors the occurrence of wildfires (Ribeiro and Walter, 2008). The rainfall seasonal difference alters the dynamics of soil chemical properties and microbiota (Lopes et al., 2011).

The majority of wildfires in the *Cerrado* are related to human ignition, when clearing pastures and opening up agricultural areas (Miranda and Sato, 2005; Di Bella et al., 2006; IBAMA, 2011). Despite its high biodiversity (Myers et al., 2000; Mendonça et al., 2008), the land conversion of *Cerrado* into pasture and crop fields has occurred at a fast rate over recent decades (Beuchle et al., 2015).

Several studies showed that the potential release of ashes into the environment can affect biodiversity in forest ecosystems and cause impacts in river communities, such as algae (Charette and Prepas, 2003), macroinvertebrates (Robinson et al., 1994; Earl and Blinn, 2003) and fishes (Minshall et al., 2001). In post-fire runoffs, nutrients and particulate materials from ashes are transported to groundwater and rivers and can accumulate in the sediment of aquatic environments, generating a potential ecological risk to benthic biota (Rand and Schuler, 2009; Wu et al., 2009; Dahm et al., 2015). In particular, severe rainfalls combined with extensive agricultural systems and drainage channels can enhance environmental risks in post-fire scenarios (Hunke et al., 2015). In this context, the effects on reproduction and development of organisms from different environmental matrices are important outcomes to be monitored in burned areas.

Fire studies in the *Cerrado* have mostly addressed the effects on vegetation (Miranda et al., 2009; Marinho and Miranda, 2013) and, to a lesser degree, on soil (Nardoto and Bustamante, 2003; Pivello et al., 2010), terrestrial invertebrates (Musso et al., 2014) and vertebrates (Briani et al., 2004; Costa et al., 2013). Therefore, ecotoxicology studies in tropical regions are needed to provide clearer insights into the potential effects of wildfires in different environmental compartments.

Thus, this paper aims to contribute to a better understanding of the effects of ashes from a wildfire on soil, subsurface water and biota. To achieve the main goal, two specific objectives were defined: (i) To evaluate the potential effects of ashes on soil and subsurface water in a recently burned area; and (ii) To evaluate the ecotoxicological effects of ashes on three different species: fish *Danio rerio* (secondary consumer, embryonic development), snail *Biomphalaria glabrata* (omnivorous, decomposer, reproduction) and a soil species *Enchytraeus sp.* (decomposer, reproduction).

2. Materials and methods

2.1. Field study area

The field study area was located inside the area of Embrapa Cerrados (CPAC), in the Sarandi river basin (30 km^2), located about 25 km northeast of the Brazilian Federal District (DF), in central Brazil. The regional climate is humid tropical-Aw (Köppen classification), with high precipitation in the summer (November and January) and a dry season in the winter (June and August). The average annual precipitation is between 1100 and 1700 mm (concentrated between September and April) and temperatures range from 22° to 27 °C (Ribeiro and Walter, 2008; Fonseca et al., 2010).

The natural vegetation from the Sarandi river basin area is typical of the savanna biome. The Sarandi river basin is composed of natural vegetation cover (approximately 40%) located basically on the erosive retreat fronts and anthropic areas (drought-based agriculture on the plateau and irrigated agriculture on the colluvium ramps) (Sousa Lima et al., 2014).

The studied areas correspond to a burned area (BA) from a wildfire in August 2013 (15°36′33,6″S and 47°43′09,1″W) equivalent to 2.6 ha and an adjacent non-burned area, named control area (CA) (15°37′07,7″S and 47°42′07,6″W), as shown in Fig. 1.

According to the type of soil and vegetation in the BA, we divided it into three sites with different vegetation physiognomies and soil types in order to highlight possible variations: S1 - *Cerrado* sensu strictu (15°36′31,3″S and 047°43′06,9″W) (wooded *Cerrado*) vegetation composed of a closed scrub and marked presence of *Andropogon gayanus* Kunth and *Brachiaria* sp. The predominant soil was Orthic Ferralsol (World Reference Base) or *Latossolo Vermelho Amarelo* (Brazilian Soil Taxonomy). This vegetation type consists of a continuous grass-forb basal cover scattered with 20–50% cover of shrubs and trees up to 6 m tall (Ribeiro and Walter, 1998); S2 - Transition landscape between Brazilian wetlands (*vereda*) and a closed scrub *Cerrado* sensu stricto (15°36′08,6″ S and 047°43′ 08,6″W). This site presented occurrence of *Mauritia vinifera* Mart and Mollic Gleysol (World Reference Base) or *Gleissolo Háplico* (Brazilian Soil Taxonomy); and, S3 - *Cerrado* sensu stricto (15°36 ‘33,6″ S and 047°43′10,0″ W) and *Latossolo Vermelho Amarelo* (Brazilian Soil Taxonomy).

2.2. Ash sampling

In order to cover the largest spatial diversity of the area, ash samples were collected carefully the day after the occurrence of wildfire. Since the ashes were not distributed homogeneously, the sample sites were selected in places with larger deposits of them. The ashes were taken to the laboratory in plastic bags, then mixed, sieved through 1-mm mesh to avoid unburned material, and stored for chemical analysis and ecotoxicological tests.