sociedade & natureza

DOI: 10.14393/SN-v34-2022- 63656
Received: October 20, 2021 | Accepted: March 31, 2022 | Published: June 03, 2022

Papers

The influence of fire on soil properties under slash-and-burn agriculture management in a hillside environment in the Atlantic Forest biome

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Keywords:
Slash-and-burn agriculture
Fire
Soil properties

Abstract
The objective of this study was to evaluate the effect of fire on the transformation of the soil's physical (granulometry and porosity), chemical (organic matter and pH) and mineralogical properties in an area where slash-and-burn farming predominates. The study was conducted in the district of São Pedro da Serra, municipality of Nova Friburgo, Rio de Janeiro state, Brazil, with relief formed by steep slopes interspersed with valleys. The region has a Tropical Altitude Climate, characterized by hot, rainy summers and mild, dry winters. The average annual rainfall is 1.279 mm, with the wettest months from November to March, and the driest months from May to August, marking the seasonal rainy (summer) and dry (winter) period. We collected deformed and undeformed soil samples at three depths (0-5 cm, 5-10 cm and 10-15 cm), in two areas, one that had been subject to high-intensity fire (HIF) and the other where traditional slash-and-burn agriculture is practiced (S&B), with low-intensity fire. The physical, chemical and mineralogical properties of the soil had distinct responses to the disruption caused by fire of varying intensity. In the HIF area, the soil was hydrophobic, accompanied by smaller pore size (microporosity). In the S&B area, in contrast, the soil had a greater percentage of macropores. The results suggest that slash-and-burn agriculture, where there are fallow intervals, less severely affects the soil properties.

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INTRODUCTION

In Brazil, few studies have investigated slash-and-burn farming on steep hillsides with poorly developed soils.

Slash-and-burn farming is viewed as sustainable because the cultivated areas are left fallow at regular intervals (with regrowth of natural vegetation). The area to be planted is cleared by cutting and burning the vegetation *in situ*. Besides land clearance, the ashes from the burning reduce the soil's acidity, making it more favorable for planting (FACHIN, 2021).

Slash-and-burn farming, also called shifting agriculture, is carried out by people in traditional rural communities or family farmers who have a close relationship with the natural forest environment. This type of farming involves cutting of vegetation followed by drying and burning of the resulting biomass, and spreading of the ashes to provide nutrients. After the planted area's fertility declines below the necessary level, it is left to fallow for an extended period before the process is repeated (PEDROSO Jr., MURRIETA & ADAMS, 2008). Slash-and-burn is one of the world's oldest farming methods, dating to between 10,000 and 12,000 years ago (MAZOYER & ROUDART, 2010).

The fallow period that is characteristic of slash-and-burn farming has positive effects on the soil properties, such as cycling of the stock of nutrients and regeneration of fertility, in comparison with the prevailing monoculture farming system, as well as maintenance of biodiversity and low land-use intensity (SANTOS *et al.*, 2021; LINTERMANI *et al.*, 2019).

The relationship between burning and soil quality is controversial. However, there is general consensus that physical, chemical, mineralogical and biological alterations (LASKAR *et al.*, 2021; XIFRÉ-SALVADÓ *et al.*, 2021; SANDEEP, NINU & SREEJITH, 2019; ULERY *et al.*, 2017) are associated with the temperature and duration of fire.

Two types of burning can be defined: a) severe burning (uncontrolled fire or incineration); and b) controlled burning of detritus for the purpose of land clearance. This latter practice is widely used with the main objective of enriching the soil with nutrients from the ashes left by burning (THOMAZ & ROSSEL, 2020).

High-intensity fire is generally associated with some negative impacts, such as increased soil loss (EFTHIMIOU *et al.*, 2020), changes in the quality of organic matter (GONZÁLEZ-PÉREZ *et al.*, 2004; CERTINI *et al.*, 2011; JIMÉNEZ-MORILLO *et al.*, 2020), hydrophobicity (HERNANDEZ, 2013, JIMÉNEZ-MORILLO *et al.*, 2017); and diminished stability of aggregates at temperatures between 250 and 550 ^{o}C (THOMAZ, 2018). This type of burning tends to be related with greater energy input.

Low-intensity fire increases the soil fertility from the ashes left afterward (NIGH & DIEMONT, 2013). According to Ketterings and Bigham (2000), low-intensity burning carried out intermittently only has a temporary effect on the soil's biological characteristics and chemical properties.

The studies conducted by Mataix-Solera and Guerrero (2007); Pereira *et al.* (2011); Xu, Lv and Sun (2012); Graham (2016); and Xifré-Salvadó *et al.* (2021) have demonstrated that low-intensity fire can minimize alterations of the soil's properties.

The presence of organic matter promotes the aggregation of soils. However, it is important to understand the role it plays when submitted to burning. According to Vogelmann *et al.* (2013), the burning of organic matter can favor hydrophobicity due to the total or partial coating of the surfaces and pores of the soil particles, which form aggregates with hydrophobic organic substances, resulting in different degrees of hydrophobicity. Besides the content, the composition of the organic matter can induce hydrophobicity, since certain compounds can influence the wettability characteristics of the soil (VOLGELMANN *et al.*, 2010).

According to De Bano (2000) and Doerr *et al.* (2005), higher fire intensity is related to increased soil hydrophobicity, while Cerdá and Lasanta (2004) reported that it is associated with greater surface runoff and Lawrence *et al.* (2007) found it to be related to loss of nutrients.

Soil hydrophobicity (or water repellency) is defined as the difficulty of wetting soil by water (DOERR, *et al.*, 2005; VOGELMAN *et al.*, 2013). This effect can be related to several variables, such as soil granulometry, type of organic matter and mineralogical composition, among others. Soil hydrophobicity can thus vary greatly typically both spatially and temporally (VOLGELMANN *et al.*, 2010; MADSEN *et al.*, 2011).

Studies of water repellency have been conducted in many parts of the world, especially in Europe (DE BANO, 2000; DOERR, 2006; BENTO-GONÇALVES *et al.*, 2012; CERDÁ *et al.*, 2012; WENINGER *et al.*, 2019), United States (WELLS, 1987; ROBICHAUD, 2000, CHEN *et al.*, 2019), and

Australia (SHAKESBY; DOERR, 2006), among others. However, the studies conducted in Europe, mainly in Spain, such as Mataix Solera and Guerrero (2007), Cerdá and Lasanta (2004) and Xifré-Salvadó (2021), have focused on low-intensity burning and its hydrological and geomorphological repercussions. There has been little research into this phenomenon in tropical environments, as well as analysis of the effect of high-intensity fire.

In Brazil, soil hydrophobicity has not been widely analyzed (THOMAZ, 2008; VOLGELMANN *et al.*, 2010; FACHIN; THOMAZ, 2013; THOMAZ; FACHIN, 2014; FACHIN *et al*, 2016; THOMAZ, 2017; BERTOLINO, 2021; FACHIN, 2021; SANTOS *et al.*, 2021). Hence, it is important to better understand hydromorphological processes. According to Thomaz (2008), studies of repellency have been increasing, mainly in relation to the role played by fire on hillsides, where after burning, alterations in the rates of infiltration and runoff have been observed (CERDÁ *et al.*, 2012).

Traditionally, research has focused only on the direct effects of burning on hydromorphological processes due to loss of forest canopy and accumulation of ashes on the soil surface (DE BANO, 2000; DOERR *et al.*, 2005). Since the 1960s, investigations have demonstrated that changes in hydromorphological processes can also be related to the soil's hydrophobicity caused by burning, because during combustion, the organic materials are vaporized and eventually reach deep layers, which tend to repel water. After a decrease in temperature, the organic materials condense, forming a coating around the soil particles, causing repellency (DE BANO, 2000).

The relationship of granulometry with hydrophobicity has been the main topic studied over the years. In this respect, a direct relationship has been observed between sandy soils and the degree of hydrophobicity, mainly in regions with dry climate. In general, variations in granulometry have been found to affect hydrophobicity (DOERR *et al.*, 2000).

Hydrophobicity can be related to the specific surface area of soil particles (WOCHE *et al.*, 2005; ALCANIZ, 2018). In this respect, the particles of sandy soils have smaller specific surface areas than those of clayey and silty soils. Doerr (2006) demonstrated that hydrophobicity of sandy soils occurs because of the greater facility of coating the coarse particles by hydrophobic substances. Doerr *et al.* (2000) reported that the most important aspect is the abundance of plant material, because the large quantity of hydrophobic organic material can coat both coarse and fine particles. Therefore, hydrophobicity is closely related to the amount of organic material in the soil.

Organic carbon is an element that can be modified by the use of fire, both in terms of quality and quantity. Depending on the intensity of the fire, the impact on the organic matter can vary from slight distillation (volatilization of the smaller constituents) to carbonization or complete oxidation (CERTINI, 2005). According to the literature, one of the central factors affecting soil is not the quantity, but instead the quality, of organic carbon. Vogelmann *et al.* (2013) demonstrated that burning of vegetation can affect the structure of substances in the soil, such as fats and oils, which are normally associated with the presence of hydrophobicity. These compounds contain a large quantity of saturated fatty acids, causing these compounds to solidify at ambient temperature. On the other hand, when the soil is heated by burning vegetation, these compounds' viscosity is reduced (ABRAMOVIC; KLOFUTAR, 1998), making them more fluid. This facilitates their distribution on the mineral particles, promoting hydrophobicity in the soil profile.

Further, in relation to organic carbon, fire raises the temperature of the surface layer and can alter the organic compounds or even form new compounds, resulting in the presence of hydrophobic organic substances that coat the soil particles and alter the soil moisture. Several researchers have reported increases of organic carbon in areas subjected to low-intensity burning, but in areas of high-intensity fire, the amount of organic carbon declines.

With regard to mineralogical alterations of the soil generated by fire, Certini (2005) reported that complete combustion is necessary, since the dehydroxylation of minerals only happens at temperatures above 500 ºC.

As is the case of the chemical and physical properties, fire affects the mineralogy only in the surface layers, rarely exceeding the depth of 8 cm. Under the effect of high-intensity fire, especially above 550 ºC, chloride-vermiculite and vermiculite can be transformed into illite, while kaolinite can be totally decomposed (ULERY *et al.*1996).

Based on the foregoing observations, the objective of this study was to evaluate the effect of high-intensity and low-intensity fire on the transformation of the soil's physical (granulometry and porosity), chemical (organic matter and pH) and mineralogical properties in a region affected by both burning intensities.

MATERIALS AND METHODS

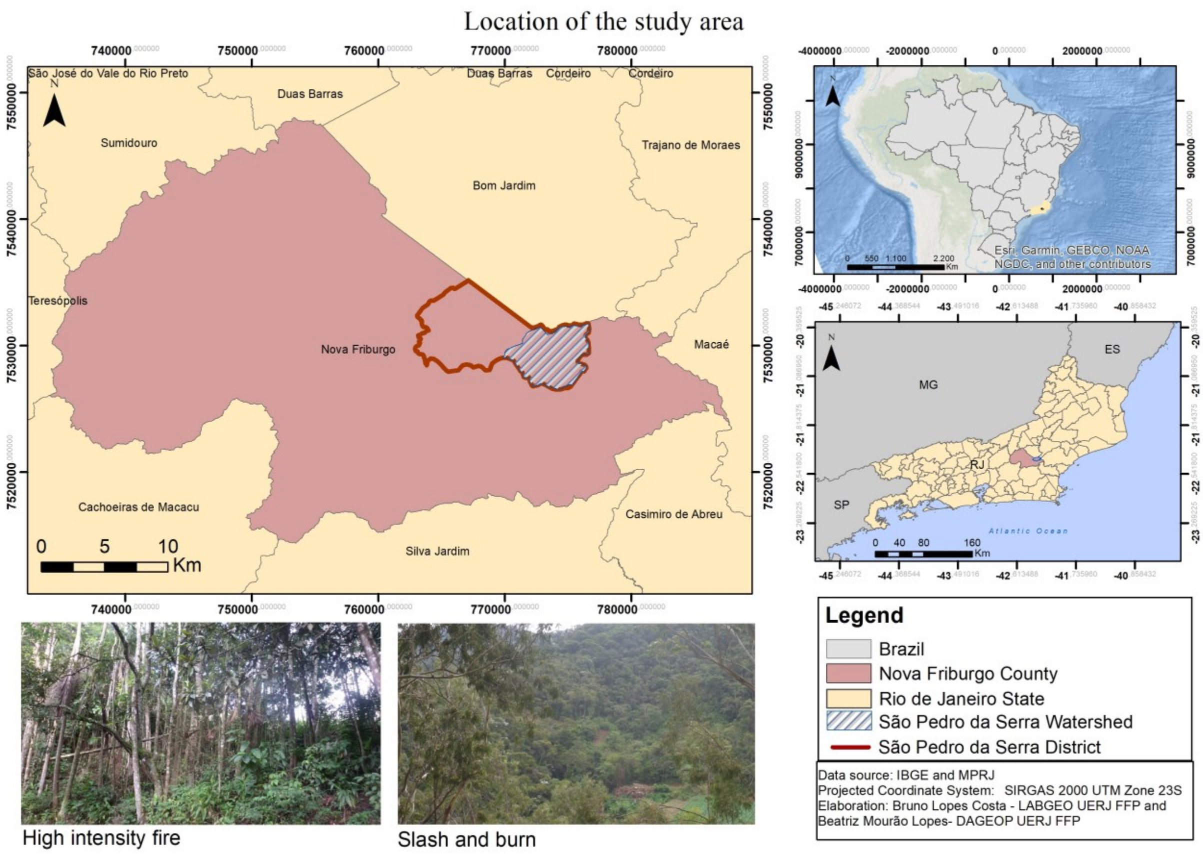
Study area

The study was conducted in São Pedro da Serra, a district of the municipality of Nova Friburgo, located in the Serra do Mar region of the state of Rio de Janeiro (geographic coordinates 22° 19' 07" S and 42° 19' 50" W, inserted in the Atlantic Forest biome, in the Macaé de Cima environmental protection area.

Slash-and-burn agriculture has been practiced in this area for over 100 years. In recent decades, the most common crops have been cassava (*Manihot suculenta*), arracacha (*Arracacia xanthorrhiza*), cauliflower (*Brassica oleracea var. botrytis*), taro (*Colocasia esculenta),* common bean (*Phaseolus vulgaris),* tomato (*Solanum lycopersicum*) and bell pepper (*Capsicum annuum Group),* varying according to the season.

Slash-and-burn farming in São Pedro da Serra occurs in three steps: 1) cutting of all plants whose diameter at breast height (DBH, measured 1.3 m above the ground) is greater than or equal to 5.0 cm, a criterion based on Federal Decree 750/93 (BRASIL, 1993), which prohibits the cutting or other suppression of primary and secondary vegetation that is native to Atlantic Forest areas with stem diameter above this limit; 2) application of low-intensity burning; and 3) cultivating the cleared area. In general, the farmers grow two or three crops before abandoning the area to allow it to recover.

Figure 1 - Location of study the area.



Source: The Authors (2022).

The climate according to the Köppen classification is Cfb (mild mesothermal, always humid with mild summers). According to Ross (1985), Nova Friburgo is located in the Atlantic orogenic belt, a strip with lithological and morphological complexity, having rocks of different types and ages, such as gneisses, migmatites, quartzites, mica schists and philites, with the secondary presence of intrusive rocks like granite and syenite. It is integrated in the Paraíba do Sul Complex – São Fidélis Unit.

The geomorphology of the municipality is predominantly composed of mountainous relief, formed by irregular terrain, in general, located on the back of the Serra do Mar escarpment. It also has steep rocky slopes reaching as high as 1,500 m, interspersed with valleys formed by fluvial erosion (DANTAS, 2000)

The main soil classes in Nova Friburgo are Litholic Neosols, inserted in the mountain/escarpment relief, Red-Yellow Latosols, and Haplic Cambisols (CARVALHO Filho *et al.*, 2000), formed from biolytic gneisses, kinzigites, and alluvial-colluvial deposits.

The soil in the study area is a Haplic Cambisol, with loamy textural class, composed of 46% sand, 28% clay and 26% silt (MERAT, 2014). This soil is classified as strongly acidic (pH ranging from 4.0 to 4.7), with carbon contents that vary from 1.6% to 1.1%, respectively.

Nova Friburgo is located in the São Pedro River sub-basin, with a high percentage of slopes with declivity greater than 45%. The component orientations are 13% to the east, 9.5% west, 9.5% north and 13.5% south. For the intercardinal points, the distribution is 10% to the northeast, 10% northwest, 9% southeast and 15.5% southwest.

The study was conducted in two areas in the district of São Pedro da Serra: a) Area A (slash and burn - S&B) – located at the coordinates 22º19' 97.61" S e 42º21'08.81" W at 711 meters above sea level, with declivity of 30º; and b) Area B (high-intensity fire - HIF) – located at coordinates 22º 19' 12.77" S; 42º 20' 37.81" W UTM, at 834 meters above sea level, with declivity of 31º.

The most recent slash-and-burn treatment occurred in July/August 2017, with the planting of sweet potatoes. The high-intensity fire in the second area occurred in the winter of 2017, when as described by local farmers, the fire for clearance to plant beans was whipped out of control by strong winds and reached an area with greater plant density, where it burned with greater intensity.

We collected samples of deformed and undeformed soil in the two areas (S&B and HIF) at depths of 5 cm, 10 cm and 15 cm. In the laboratory, we analyzed the granulometry, total porosity, macroporosity, microporosity, pH and repellency, with five repetitions at each depth, for a total of 15 samples per assay for each area. The mineralogical analysis was performed on a single sample from each area and depth. The samples were collected in July (dry season). For general characterization of the soil, we dug a small trench in each area, in the middle of a hillside.

After opening the trenches, we examined the horizons by comparison with pedological material, according to the method of Embrapa (2006).

The granulometry was measured by the pipette method (EMBRAPA, 1997). The deformed samples were homogenized and separated into aliquots of approximately 2 kg.

To measure the macroporosity, microporosity and total porosity, we used the tension table method (OLIVEIRA; PAULA, 1983; EMBRAPA, 1997) and apparent density method (EMBRAPA, 1997). For these tests, we collected undeforemed samples using kopeck rings with volume of 50 cm^3.

The mineralogical characterization of the sand and clay fractions was performed by X-ray diffractometry (XRD). The diffractograms were obtained by determination of the interplanar spacing based on the powder method, utilizing a Bruker D4 Endeavor® diffractometer under the following operating conditions: Co Kα radiation (35 kV/40 mA); and goniometer speed of 0.02º (2θ) per scan with 1 second for each scan, collected from 4 to 80º (2θ). The qualitative interpretation of the spectra was based on comparison with the standards contained in the PDF02 database (ICDD, 2006), with the Bruker Diffrac Plus software.

The degree of hydrophobicity was measured by two methods, as described by King (1981). The first, called water drop penetration time (WDPT), consisted of applying water droplets (40 µL) with a Pasteur pipette and measuring the time elapsed for the droplets to completely penetrate the sample. The repellency degree was assigned according to the method of Bisdom *et al.* (1993), as reported in Table 1. The second method was measurement of the molarity of ethanol droplets (MED), where two droplets of an aqueous solution of ethanol (40 µL) at a known concentration was placed on the sample and the time necessary for them to be absorbed by the sample was measured. This procedure can be applied with concentrations ranging from 0 to 5 mol l^{-1}, with intervals of 0.2 mol l^{-1}. The hydrophobicity was verified by the molarity of the ethanol solution at which the droplets penetrate the surface of the sample in under 10 seconds. The test was performed only with the samples that presented repellency by the WDPT method (>10 seconds).

Table 1 – Classification of water repellency

Classification	Water repellency (seconds)
Wettable or non-water-repellent soil	< 5
Slightly water repellent soil	5 – 60
Strongly water repellent soil	60 -600
Severely water repellent soil	600-3600
Extremely water repellent soil.	> 3600

Source: Bisdom *et al.* (1993).

RESULTS AND DISCUSSION

The soil from the HIF area had larger proportions of the sandy fraction along the profile than the soil from the S&B area, with 555 g/kg^{-1} at 0-5 cm, 574 g/kg^{-1} at 5-10 cm and 596.9 g/kg^{-1} at 10-15 cm. In turn, the soil in the S&B area had sand fractions of 434 g/kg^{-1} t at 0-5 cm, 486 g/kg^{-1} at 5-10 cm and 456 g/kg^{-1} at 10-15 cm.

The silt fractions in the soil samples from the two areas were very heterogeneous. At all the depths in the S&B area, the quantity of silt found was more than two-fold greater than that in the HIF area.

The HIF area's soil showed progressive increase in the clay fractions with greater depth: 222.5 g/kg^{-1} at 0-5 cm, 224.5 g/kg^{-1} at 5-10 cm and 234.0 g/kg^{-1} at 10-15 cm. In contrast, in the S&B area, the values found were 101.0 g/kg^{-1} at 0-5 cm, 148.1 g/kg^{-1} at 5-10 cm and 117.8 g/kg^{-1} at 10-15 cm (Table 2).

Table 2 – Total sand, silt and clay (g/kg^{-1}) in the soil of the HIF and S&B areas

Area	Granulometry (g/kg-1)					
	Depth (cm)	**CS**	**FS**	**As**	**S**	**Cl**
HIF	0 – 5	461.2	93.5	555	222.2	222.5
HIF	5 – 10	455.2	118.3	574	180.3	224.5
HIF	10 – 15	466.4	130.5	596.9	169.1	234.4
S&B	0 – 5	287.6	146.4	434	459.6	101
S&B	5 – 10	335.3	148.3	486	368.3	148.1
S&B	10 – 15	340.3	116.1	456	432.5	117.8

Notes: HIF = High-Intensity Fire, S&B: Slash-and-burn, CS: Coarse sand, FS: Fine sand, Sa: Sand, S: Silt, Cl: Clay

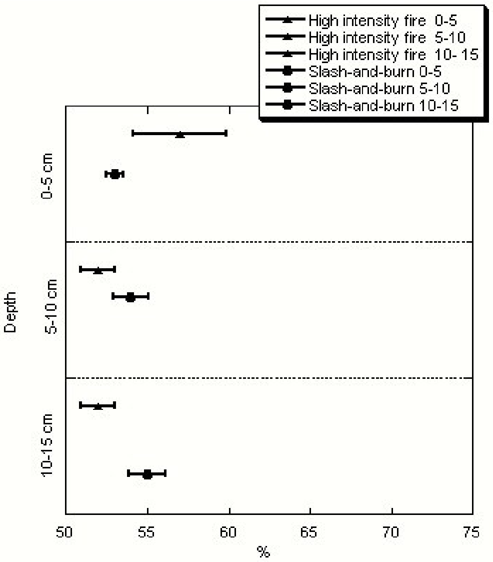
Source: The authors (2022).

According to Ferreira (2010), the size of particles can influence the process of water percolation in the soil. Soils with coarser granulometry tend to permit faster infiltration. The greater percentage of fine sand in the S&B area was likely responsible for the low hydraulic conductivity found in this area (MERAT, 2014).

In relation to total porosity, the soils in the two areas had high and homogeneous values at the three depths studied (Figure 2). The top layer in the HIF area had the greatest total porosity, reaching a value of 57.1%.

According to Mataix-Solera and Guerrero (2007), soil porosity is a crucial factor in heat distribution. Soils with greater porosity, especially macropores, favor the transmission of the energy released by combustion.

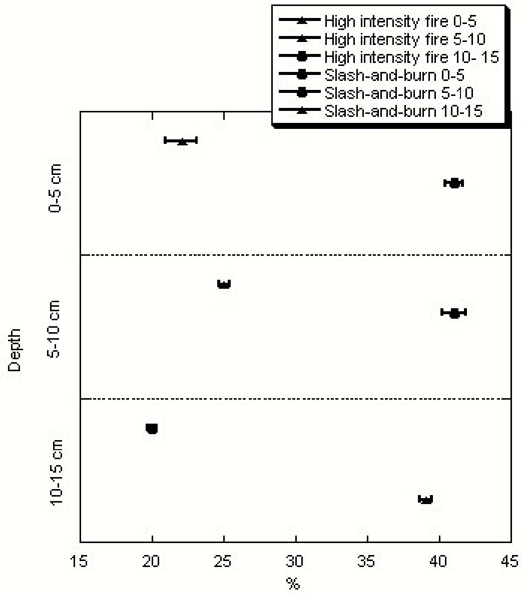
Figure 2 – Soil total porosity at different depths in HIF and S&B areas



Source: The authors (2022).

Macroporosity is intrinsically related to the circulation of water in the soil. Thus, its values are fundamental to help understand the behavior of water in the soil. The percentage of macropores found in the S&B area, associated with the values of sand greater than 430 g/kg^{-1}, were factors favoring faster water percolation in the soil (Figure 3).

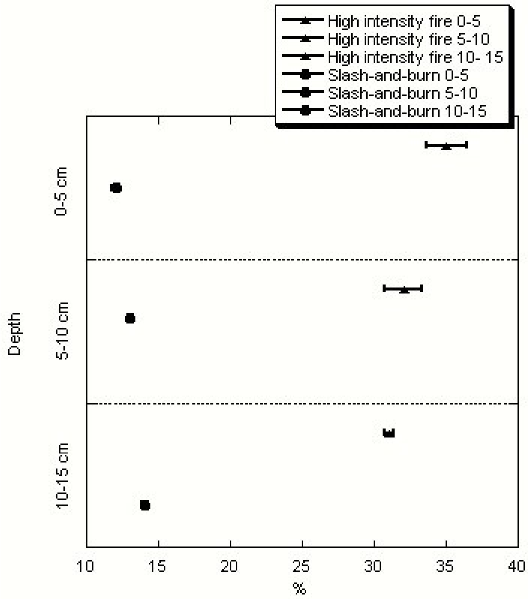
Figure 3 – Soil macroporosity at different depths in the HIF and S&B areas.



Source: The authors (2022)

With respect to microporosity, the soil in the HIF area had the highest overall percentage of micropores (Figure 4). The top layer (0-5 cm) contained the highest percentage of micropores, 35%, followed by 32% at 5-10 cm and 31% at 10-15 cm. In the S&B area, the corresponding percentages were less than half of those found in the HIF area: 12% micropores at 0-5 cm; 13% at 5-10 cm; and 14% at 10-15 cm.

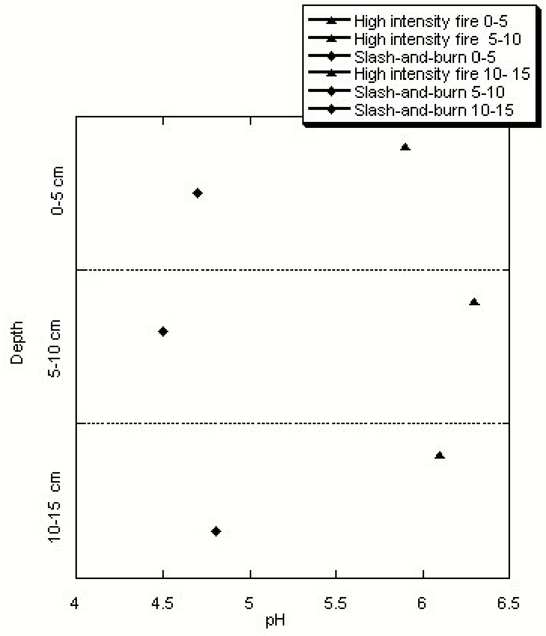
Figure 4 – Soil microporosity at different depths in the HIF and S&B areas



Source: The authors (2022)

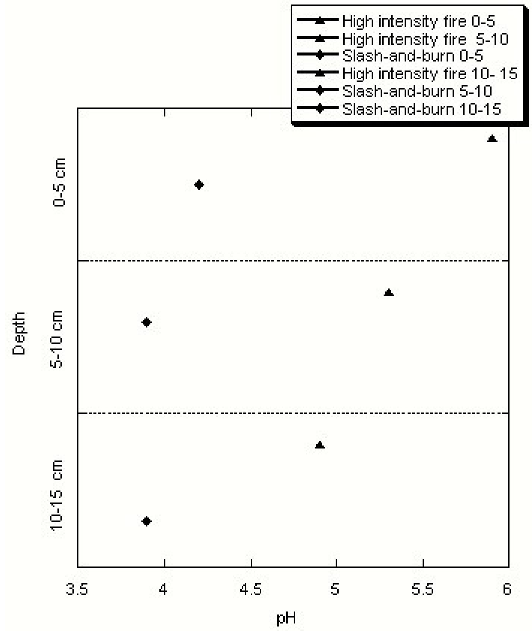
The pH results of the soil measured in water (Figure 5) and KCl (Figure 6) showed that the soil in the S&B area had greater acidity than that in the HIF area. The pH values measured in water at the three soil depths in the S&B area were 4.5 at 0-5 cm, 4.4 at 5-10 cm and 4.7 at 10-15 cm. In contrast, the soil that underwent total combustion had pH values of 6.0 at 0-5 cm, 6.2 at 5-10 cm and 6.0 at 10-15cm. The pH values found in the S&B area were near those reported by Queiroz (2007) and Merat (2014) in studies of abandoned S&B areas in the São Pedro River Basin.

Figure 5 – Soil pH measured in water at different depths in the HIF and S&B areas



Source: The authors (2022).

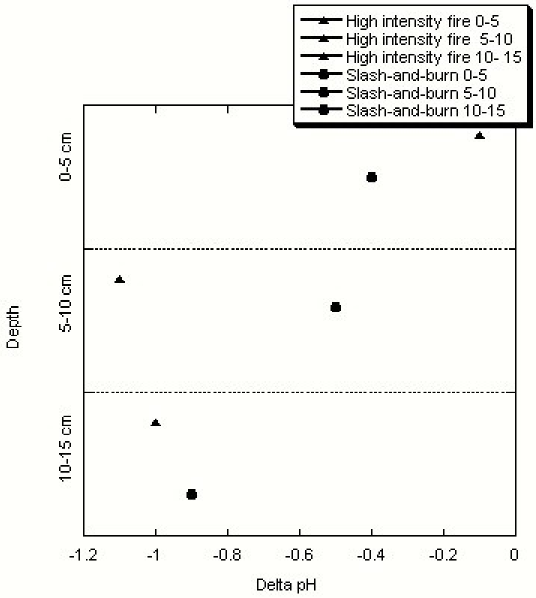
Figure 6 - Soil pH measured in KCl at different depths in the HIF and S&B areas



Source: The authors (2022).

By subtracting the pH value in KCl from the pH in water, it was possible to measure the ΔpH of the soil. In both areas and all depths, the ΔpH was negative. The 0-5 cm depth in the HIF area had the value closest to zero, of 0.17. The corresponding value at depth of 5-10 cm was –1.10 and that at 10-15 cm was -1.03. In the S&B area, the ΔpH values were -0.43 at 0-5 cm, -0.50 at 5-10 cm and -0.87 at 10-15 cm (Figure 7). According to Prado (1991), negative ΔpH means the predominant presence of negative charges in the soil, and consequently greater capacity to retain cations (calcium, magnesium, potassium and sodium) than anions.

Figure 7 – Soil ΔpH at different depths in the HIF and S&B areas



Source: The authors (2022).

The results obtained by the WDPT and MED are reported in Table 1. The water repellency degree of the samples according to the two tests varied from not significant to moderate. The soil in the 0-5 cm layer in the HIF area had the greatest repellency. In this sample, the time necessary for the droplets to infiltrate the soil was 180 seconds, so the repellency degree of this soil can be classified as 6-8, and the severity as moderate. The results obtained via the MED test also indicated repellency only at the 0-5 cm depth in the HIF area, classified as moderate severity (Table 3). This demonstrated the correlation between sandy texture and water repellency. According to Wallis and Horne (1992), higher repellency values are related to sandy soils. The authors reported that the hydrophobicity characteristics of sandy soils occur due to the easier coating of sand particles by hydrophobic substances, given the small specific surface area of these particles.

Table 3 –Water repellency according to the MED and WD tests in the HIF and SB areas

Area	Depth (cm)	MED (mol L⁻¹)	WD (s)	Water repellency
HIF	0-5	1.8	180	Slightly water repellent soil
HIF	5-10	0.4	<1	Wettable or non-water-repellent soil
HIF	10-15	0.2	<1	Wettable or non-water-repellent soil
S&B	0-5	0.2	<1	Wettable or non-water-repellent soil
S&B	5-10	0.2	<1	Wettable or non-water-repellent soil
S&B	10-15	0.2	<1	Wettable or non-water-repellent soil

Source: The authors (2022).

Another factor affecting the hydrophobicity of the soil in the HIF area was the ashes, because according to Mataix-Solera and Guerrero (2007), temperatures above 200 °C tend to consume organic matter, generating whitish ashes that can contain hydrophobic substances, forming an impermeable layer. This phenomenon can be perceived by the porosity values, where the HIF soil, although having similar total porosity in the 0-5 cm layer, had a greater percentage of micropores than in the S&B soil at this same depth. In turn, the S&B soil had the highest percentage of macropores in the two areas and at all depths.

According to Certini (2005), very high temperatures (generally above 500 °C) are necessary to cause mineralogical alterations in soils. The XRD results indicated relative homogeneity of the mineralogical composition of the sand fraction, composed basically of quartz, kaolinite, muscovite and gibbsite, in both areas and at all depths. In turn, the clay fraction in the S&B soil at the three depths also contained illite and sepiolite. These minerals were not found in the HIF soil (Table 4).

Table 4 – Minerals of the sand fraction of soil in the HIF and S&B areas according to stereomicroscope.

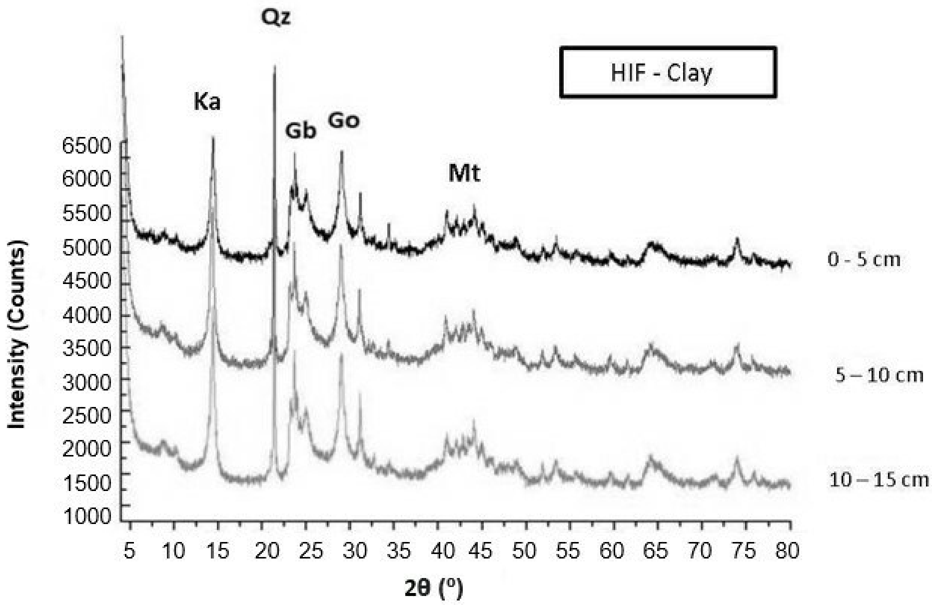
Area	Depth (cm)	Mineralogy	
		Coarse Sand	**Fine Sand**
HIF	0-5	quartz, feldspar, muscovite, biotite, garnet.	quartz, feldspar, ilmenite, phlogopite, muscovite.
HIF	5-10	quartz, feldspar, biotite, garnet.	quartz, feldspar, ilmenite, phlogopite, muscovite.
HIF	10-15	quartz, feldspar, garnet.	quartz, feldspar, ilmenite, phlogopite, muscovite.
S&B	0-5	quartz, feldspar, muscovite, biotite.	phlogopite, muscovite, biotite.
S&B	5-10	quartz, feldspar, phlogopite, biotite, orthoclase.	phlogopite, quartz, garnet, biotite, orthoclase.

Source: The authors (2022).

Further according to Certini (2005), the reduction of gibbsite occurs in areas subjected to severe burning. The overlap of the diffractograms shows alterations in the behavior of gibbsite according to the depth, indicating that fire might have been responsible for this behavior, especially in the 0-5 cm layer, since the surface is most subject to the effects of combustion (Figure 8).

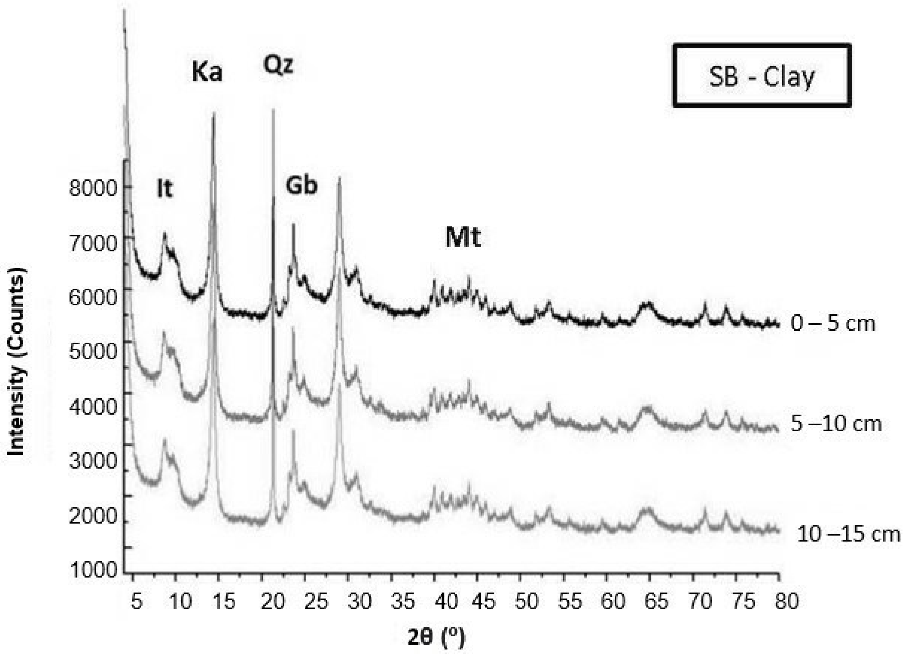
The overlap of the diffractograms of the clay fraction of the soil in the HIF area indicates no changes occurred in the peaks of the mineralogical composition due to the fire (Figure 9).

Figure 8 – Overlap of X-ray diffractograms of the clay soil fraction in the HIF area. Co Kα radiation (35 kV/40 mA). Ka – Kaolinite, Qz – Quartz, Gb – Gibbsite, Go – Goethite, Mt – Muscovite.



Source: Elaborated by the authors (2022).

Figure 9 – Overlap of X-ray diffractograms of the clay soil fraction in the S&B area. Co Kα radiation. It – Illite, Ka – Kaolinite Qz – Quartz, Gb – Gibbsite, Mt – Muscovite.



Source: Elaborated by the authors (2022).

Quartz and kaolinite were found in both areas. The occurrence of quartz is common because it is extremely resistant to weathering. In turn, kaolinite is an aluminum hydroxide mineral often found in tropical soils due to the chemical weathering of feldspar by the plentiful rainwater. Of particular note is the presence of hematite in the top layer in the HIF area. The occurrence of this mineral was not observed in the other two layers of this area (Table 3).

A test with a handheld magnet in the sand fraction indicated the presence of magnetic minerals in the top layer of the HIF area, which was not found in the other samples. Ketterings *et al*.,(2000) reported the reduction of gibbsite and the conversion of goethite into ultrafine magnetite, an iron oxide alloy that forms by thermal transformation at temperatures between 300 and 425 °C.

CONCLUSION

We found differences in the behavior of the mineralogical and physical properties of the soil when exposed to the two different fire intensities.

The presence of high-intensity fire caused greater disturbances in the soil, along with hydrophobicity and greater percentages of micropores. In contrast, in the slash-and-burn area (subject to low-intensity fire), the soil had a greater percentage of macropores.

Therefore, blaming the degradation of soil and the environment only on the practice of slash-and-burn farming in the district of São Pedro da Serra (Nova Friburgo, Rio de Janeiro) seems to be mistaken, since we observed the most intense transformations in the soil subjected to high-intensity fire.

FUNDING SOURCE

This study received financing from the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), process 483495, Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ), process E-26/111.897/2021, and the Universidade do Estado do Rio de Janeiro –Programa de Apoio à compra ou Manutenção de Equipamento e à Pequenas Reformas PROINFRA UERJ 2021 nº 01/2021 .

ACKNOWLEDGMENTS

To the Universidade do Estado do Rio de Janeiro (UERJ). To the farmers of São Pedro da Serra, in particular, Geraldo V Antoir Neves, Hil Cesar Schimidt, Idineia Machado Figueira Schimidt, Maria Aparecida Carriello Fréz and Patrícia Figueira Schimidt, who were fundamental in the stages of field monitoring. Without their help, this work would not have been carried out. I also thank this work to Jovenir Boy (in memorium), Jorge Boy and Sergio Boy for making experimental areas available and all the students who participated from 2005 onwards, based on a direct partnership or work research contract (CNPq and FAPERJ) and government agencies are to carry out some way to carry out this study.

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AUTHORS' CONTRIBUTION

Bruno Souza de Mattos collected and wrote the text. Ana Valére Allemão Bertolino conceived the study, collected, provided and wrote the text. Luiz Carlos Berto conceived the study of data, texts and wrote.