SOILS

Temporal evaluation of soil chemical attributes after slash-and-burn agriculture in the Western Brazilian Amazon

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ABSTRACT. In Amazonia, the main causes of deforestation are systems based on slash-and-burn agriculture. The objective of this work was to evaluate temporal changes in the soil chemical attributes after the vegetation has been slashed and burned in an area of native forest in the Western Amazon. For this study, four hectares of forest in Cruzeiro do Sul, State of Acre, Brazil, was slashed and burned. The soil in the study area was classified as Ultisol (Argissolo Amarelo Distrófico típico). Soil samples were collected over the course of one year, the first one being collected 16 hours after the burn and the others at 30, 60, 90, 150, 210, 270, and 360 days after the burn. The soil surface layers were more sensitive to fire action. Ashes from vegetation burn increased pH values, basic cations, and C values only in the first months, resulting in higher basal saturation values (V%). The practice of slash-and-burn after 12 months resulted in lower values of pH, Ca, Mg, K, and P and higher values of Al and H, as well as saturation by aluminum in the soil, indicating this practice contributes to the reduction of soil fertility.

Keywords: amazonian agroecosystem; soil fertility; cycling of nutrients; soil management; Brasil.

Introduction

The Amazon region comprises an area of approximately six million km^2, representing 40% of the rainforest areas of the world, occupying most of the Brazilian territory, and extending into the neighboring countries (Laurance et al., 2001). This region has a great diversity of environments with mosaics of multiple vegetation and habitat types whose balance depends on the climate, water quality, soil, nutrient cycling, and other environmental characteristics. However, this ecosystem is fragile, with most of the soils heavily leached and weathered, usually with a dystrophic character (low saturation by bases) and often with high levels of Al in addition to low saturation by bases (Anjos & Pereira, 2014).

Located in the western portion of the Amazon, the State of Acre has many areas that are difficult to access, resulting in a lack of information on its natural resources. The main cause of deforestation is the farming system followed by the Amazonian family farmers for their livelihood. This system is based on slash-and-burn agriculture, which is the practice of preparing an area for planting by cutting, drying, and burning the natural vegetation in a patch, which is then used for cultivation for a short period of time, after which it is left fallow for a long duration (Pedroso Júnior, Murrieta, & Adams, 2008; Morton et al., 2008). The ashes resulting from the burn contain nutrients accumulated by the vegetation, which fertilizes the soil and acts as an acidity corrector. This practice is low cost and easy to adopt and has persisted due to the low fertility of most soils in the region, the high cost of fertilizers and correctives, and the lack of adequate policies to foment and provide relevant technical assistance to this segment of producers.

The dynamics of nutrients under the slash-and-burn agricultural system in the Amazon have been studied by several authors (Longo & Espíndola, 2000; McGrath, Smith, Gholz, & Oliveira, 2001; Johnson, Vieira, Zarin, Frizano, & Johnson, 2001; Fearnside & Barbosa, 1998; Fearnside, 2005; Markewitz, Davidson, Moutinho, & Nepstad, 2004; Zarin et al., 2005; Davidson et al., 2007; Araújo, Ker, Mendonça, Silva, & Oliveira, 2011; Braz, Fernande, & Alleoni, 2013) Many of these studies have focused on changes in the soil

nutritional status after slash-and-burn, but few relate the soil nutrient dynamics over time. Evaluating carbon and nutrient stocks in the Amazon, Johnson et al. (2001) conclude that the effects of slash-and-burn on C, N, and basic cation stocks are not sufficient to compromise secondary forest growth in the Amazon, although the area under study has undergone several cycles of slash-and-burn cultivation.

In the short term, fire becomes a mineralizing agent, increasing the availability of nutrients for plant growth, especially at soil depths of less than 0.5 cm, due to the high concentration of P, K, and Ca in the ashes (Kauffman, Cummings, & Ward, 1994). In a study analyzing soil attributes after conversion of forest to pasture in the Amazon, Braz et al. (2013) found that the pH values and the availability of P, Ca, and K in the soil increased, and the levels of exchangeable Al decreased. Nevertheless, the fragile balance of the system's nutrient cycling is compromised after the early burn of felled vegetation, since nutrients that are not absorbed rapidly by the recolonizing vegetation will be leached and irreversibly lost (Sanchez, Bandy, Villachica, & Nicholaides, 1982). Negative impacts are expected and are severe, since the basic mechanisms of natural ecosystem functioning, with their effective recycling of organic matter and nutrients, are broken (Kauffman, Cummings, Ward, & Babbitt, 1995).

The objective of this work was to evaluate temporal changes in the soil chemical attributes after vegetation slash-and-burn, in an area of native forest in the Western Amazon.

Material and methods

The study was carried out in the municipality of Cruzeiro do Sul, State of Acre (7°45'S and 72°22'W), in the Brazilian Western Amazon region, Brazil (Figure 1). The climate of the region according to the Köppen classification is type Am, hot and humid equatorial. The average annual rainfall is 2,280 mm, with average monthly values of 66 to 299 mm, and the average annual temperature is 24.9°C (Carvalho et al., 2016). The selected area is in a smooth-wavy relief, with an altitude of 210m, and the soil is classified according to the Brazilian Soil Classification System (BSCS) as typical Dystrophic Yellow Argisol (Santos et al., 2013).
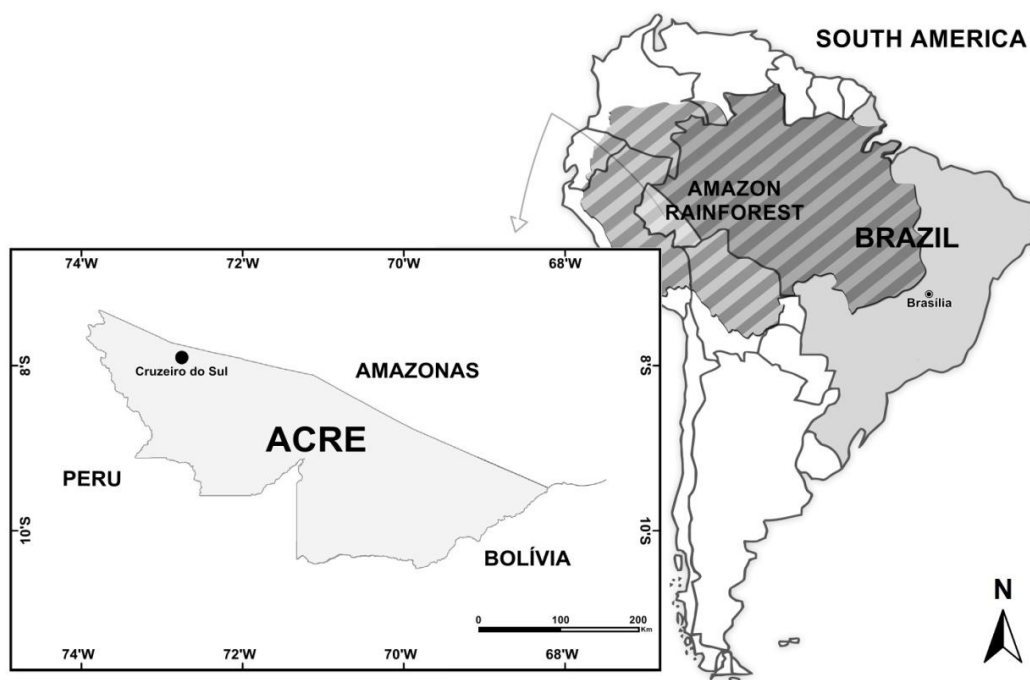
Figure 1. Location of the municipality of Cruzeiro do Sul, State of Acre in the Brazilian Western Amazon. (Adapted from: Medeiros et al., 2015).

For this study, the forest was cleared and burned in an area of four hectares, in which only the central hectare was sampled and subdivided into plots of 50 × 20m (Figure 2). Eight soil samples were collected over the course of one year. The first was collected 16 hours after the burn, and the remaining were collected 30, 60, 90, 150, 210, 270, and 360 days after the vegetation slash-and-burn on the dates 10/01/2010, 11/01/2010, 12/01/2010, 02/01/2011, 04/01/2010, 06/01/2011, and 09/01/2011, respectively. In addition, samples were collected from the undisturbed forest area. For the sampling, three trenches

($1 \times 1 \times 1$ m) were randomly distributed within each subplot of 100 m^2 in the central hectare of the evaluation area, from which samples were collected at seven depths (0-0.05, 0.05-0.10, 0.10-0.15, 0.15-0.20, 0.20-0.30, 0.30-0.40, and 0.40-0.50 m). The subsamples were pooled to form a composite sample for each treatment in the sampled area.
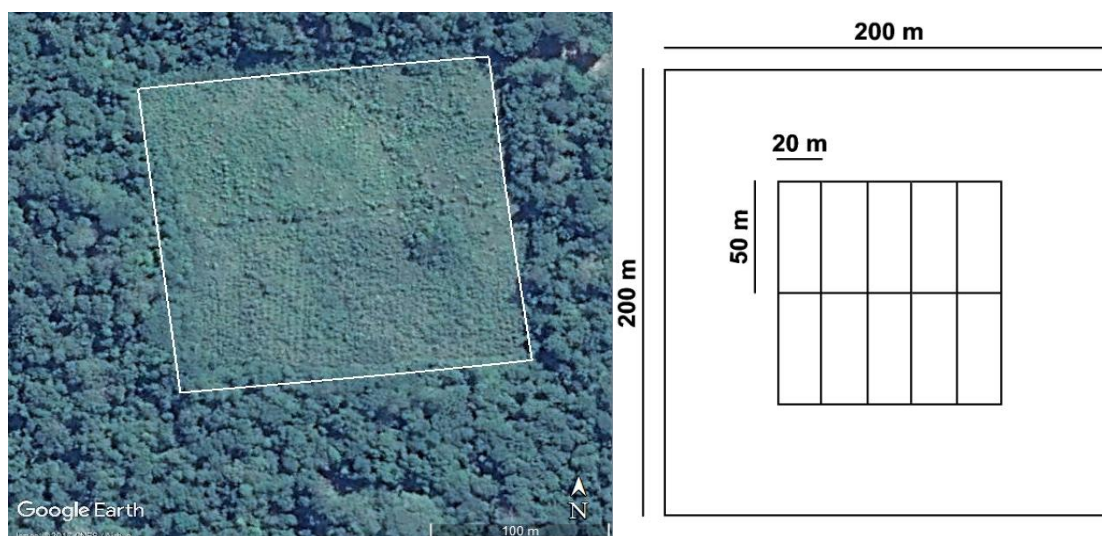
Figure 2. Study area after vegetation slash-and-burn (coordinates: 7°45'43.00"S and 72° 22'51.00"W) and sampling design. Source: Google Earth (retrieved on Oct. 20, 2017 from https://www.google.com/earth/).

After collection, the samples were dried in the shade and passed through a 2 mm sieve to obtain air-dried fine earth (ADFE) used in the analysis. The pH values were determined in H_2O, in a soil: water suspension of 1:2.5; aluminum (Al^{3+}, calcium (Ca^{2+}), and magnesium (Mg^{2+})), were extracted with 1 mol L^{-1} KCl solution in the proportion of 1 part soil to 10 parts solution; potassium (K^+), sodium (Na^+), and phosphorus (P), were extracted with 0.05 mol L^{-1} HCl solution and 0.0125 mol L^{-1} H_2SO_4, in the proportion of 1 part soil to 10 parts solution, where K^+ and Na^+ were determined by flame photometry and P by colorimetry; potential acidity (H + Al) was extracted with 1 mol L^{-1} calcium acetate solution according to Donagema, Campos, Calderano, Teixeira, and Viana (2011). From the results, sum values of exchangeable bases (SBs), cation exchange capacity (T), base saturation (V%), and aluminum saturation (m%) were calculated. To determine the organic carbon content (C), the samples were ground and passed through a 0.2 mm sieve, and carbon was determined by organic matter oxidation by potassium dichromate ($K_2Cr_2O_7$) at 0.2 mol L^{-1} in sulfuric medium, and titrated using 0.1 mol L^{-1} ammonia ferrous sulfate following the methodology of Yeomans and Bremner (1988). The determination of the total nitrogen content (N) in the soil samples was done by the Kjeldahl method, described by Tedesco, Gianello, Bissani, Bohnen, and Volkweiss (1995).

The results were submitted to analysis of variance, and the means were compared by the Tukey's test (p < 0.05).

Results and discussion

The soil chemical attributes differed significantly between samples collected at different times (Figures 3, 4, and 5), showing the influence of burning on nutrient dynamics over time. The greatest variations were observed in the superficial layers, up to the depth of 0.20 m. In the layers that were 0.30-0.40 and 0.40-0.50 m deep, similar values were noted for samples collected at different times, with no statistically significant difference between them or when compared to the area before burning. The pH values in water ranged from 5.38 (0-0.05 m) to 4.95 (0.40-0.50 m) in the forest area and showed a significant increase immediately after burning. Intense biological activity, combined with the hot and humid environment that predominates in the Amazon region, promotes greater CO_2 production in the soil solution. This CO_2 acts as a source of acidity, resulting in intense acidification, and as the driving force in the processes of chemical weathering (Bohn, Mcneal, & O'connor, 2001; Dias-Filho, Davidson, & Carvalho, 2001). This acidification can explain the soil pH values below 5.0 that were observed at greater soil depths.

At the depths of 0-0.05 and 0.05-0.10 m, the pH, 30 days after burning, reached values of 5.88 and 5.76, respectively, reflecting the immediate corrective effect of the ashes on soil acidity. Several authors report significant increases in soil pH after biomass slash-and-burn (McGrath et al., 2001; Silva, Silva, & Melo, 2006; Araújo et al., 2011; Braz et al., 2013). When the base-rich ashes are incorporated into the soil, the

H^+ ions are dissociated from the exchange complex, and the basic cation content is adsorbed to clay surfaces, which helps raise the pH values. These results may also be associated with the rapid mineralization of organic matter, resulting in a higher release of organic acids that may be complexing in the initial months, as Al^{+3} and H^+ ions are responsible for soil acidity. However, in the subsequent period, there was a reduction in pH values related to the high rainfall conditions of the region, and under these conditions, a noticeable loss of nutrients by leaching occurs.
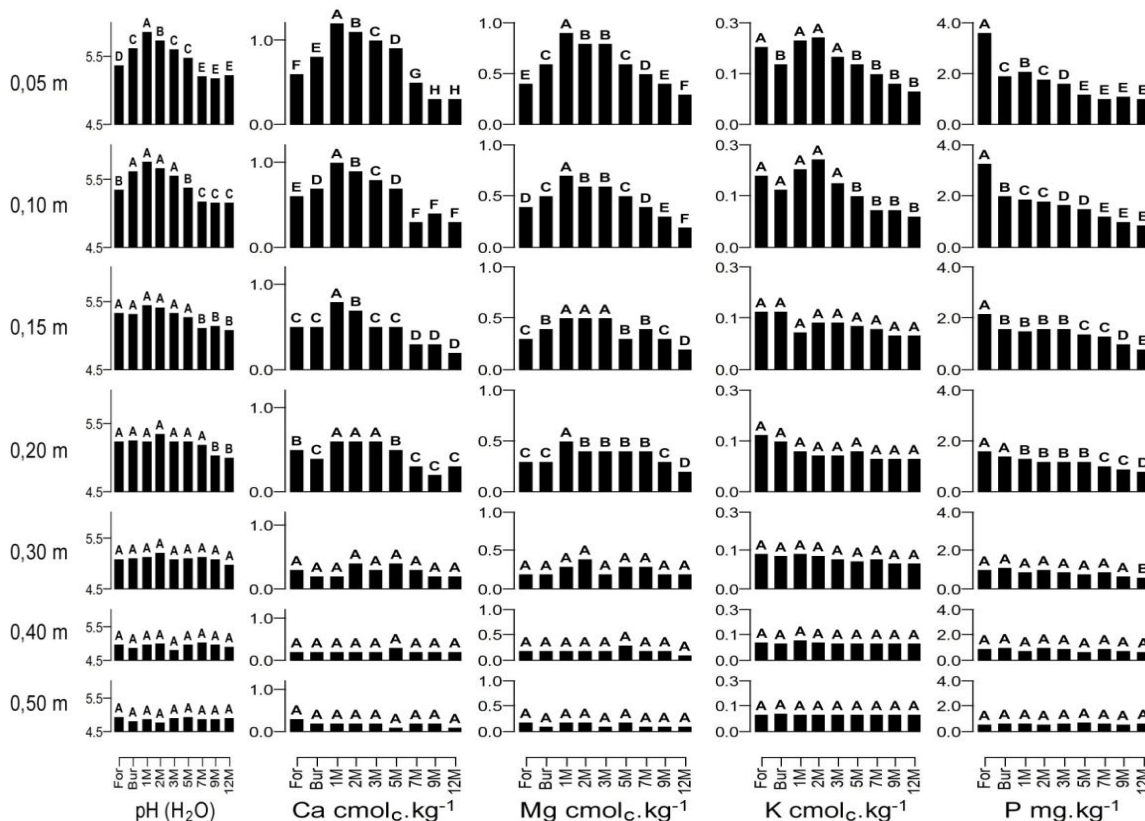
For – Forest before burning, Bur – 16 hours after burning; 1M – 1 month, 2M – 2 months, 3 M – 3 months, 5M – 5 months, 7M – 7 months, 9M – 9 months, and 12M – 12 months after burning.

Figure 3. Mean values of pH in water and calcium (Ca), magnesium (Mg), potassium (K), and phosphorus (P) content at different depths, sampled at different times. Means followed by the same letter do not differ by Tukey's test ($p < 0.05$).

The variations observed over time for Ca^{2+} content and Mg^{2+} content showed similar patterns, with significant differences up to the depth of 0.20 m. We verified that burning the vegetation resulted in an increase in the content of these elements, especially in the 0-0.05 and 0.05-0.10 m layers, for up to 30 days, which was followed by a rapid decrease until the last collection, at 360 days after burning. These results reflect the fragility of the system after vegetation removal, which indicates loss of nutrients by leaching under conditions of high temperature and intense rainfall. Nutrient cycling in tropical forests involves a complex set of direct and indirect feedback mechanisms between soil and vegetation (Ferreira, Luizão, Miranda, Silva, & Vital, 2006). Vegetation burn results in an imbalance of this system, causing an increase in the soil fertility only in the first months, with negative effects in the long term. Similar results from other studies in the Amazon region have been reported by Braz et al. (2013), Orrutéa, Melo, Motta, and Lima (2012), Numata, Soares, and Leonidas (2002), and McGrath et al. (2001).

For K^+, unlike Ca^{+2}, and Mg^{+2} values, no significant increase in its content was observed when compared to the forest area at any of the collection periods. At the fifth month after burning, the values of this nutrient presented a significant reduction in the 0-0.05 and 0.05-0.10 m layers, which remained until 360 days, with a mean of 0.11 $cmol_c$ kg^{-1}. The release patterns of the nutrients contained in the ashes can vary considerably among nutrients. Due to its higher solubility, K is more susceptible to leaching because it has an extremely rapid release rate. In a study on nutrient cycles in the Amazon, Vitousek (1984) has reported that 80% of the K can be lost in the first 30 days of plant material decomposition; on the contrary, elements linked to the structure of leaves, such as Ca^{2+},

and to a lesser extent Mg^{2+}, may present an initial accumulation phase, with a later release phase. Some authors report K^+ levels increase in the conversion of forest areas to pastures in the Amazon region, but this pattern is related to cycling through animal excreta (Braz et al., 2013; Araujo et al., 2011; Couto, Klamt, & Stein, 2000).

P levels showed high sensitivity to fire action, especially in the superficial layers. The forest area presented a mean value of 2.9 mg kg^{-1} up to the depth of 0.15 m. At 360 days, at the same depth, the mean value was 1.1 mg kg^{-1}. The reduction of soil pH and the increase in Al^{+3} concentration (Figure 4) increase the adsorption sites of this macronutrient to the Fe and Al oxides and hydroxides of the soil, thus reducing its availability. In a similar study under laboratory conditions, Galang, Markewitz, and Morris (2010) found results indicating that in the 0-0.05 m soil layer, organic P stocks are converted to inorganic P, and this conversion declines with increasing temperature and time. The slash-and-burn of forests leaves the soil surface prone to erosion, and since a large part of the amount of phosphorus available to plants is present in this layer, soil losses can result in large losses of this macronutrient.

Except for the samples collected at 30 and 60 days in the 0-0.05 m layer, a reduction in the organic carbon content (C) was observed when compared to the forest before the burn (Figure 4). This reduction can be attributed to the high temperatures caused in the soil by the forest burn, which accelerates the mineralization of soil organic matter and causes the loss of C as CO_2 and CH_4 to the atmosphere (Davidson, Verchot, Cattanio, Ackerman, & Carvalho, 2000; Cerri, Volkoff, & Eduardo, 1985). The high temperatures also eliminate much of the soil C contained in the microbial biomass, which could be related to the observed results. Another factor is that forest burn reduces C inputs in the soil that come from the litter and the roots, causing the output rate of C to be higher than the input, and reducing its soil content as a function of time. The increase of C levels at 30 and 60 days can be explained by the resumption of microbial activity due to the momentary increase of more labile forms of C generated by mineralization of organic material after the forest burn. The microbial species are also consumed and their levels reduced as a function of time due to the lack of organic material entry into the system to ensure organic matter stability.
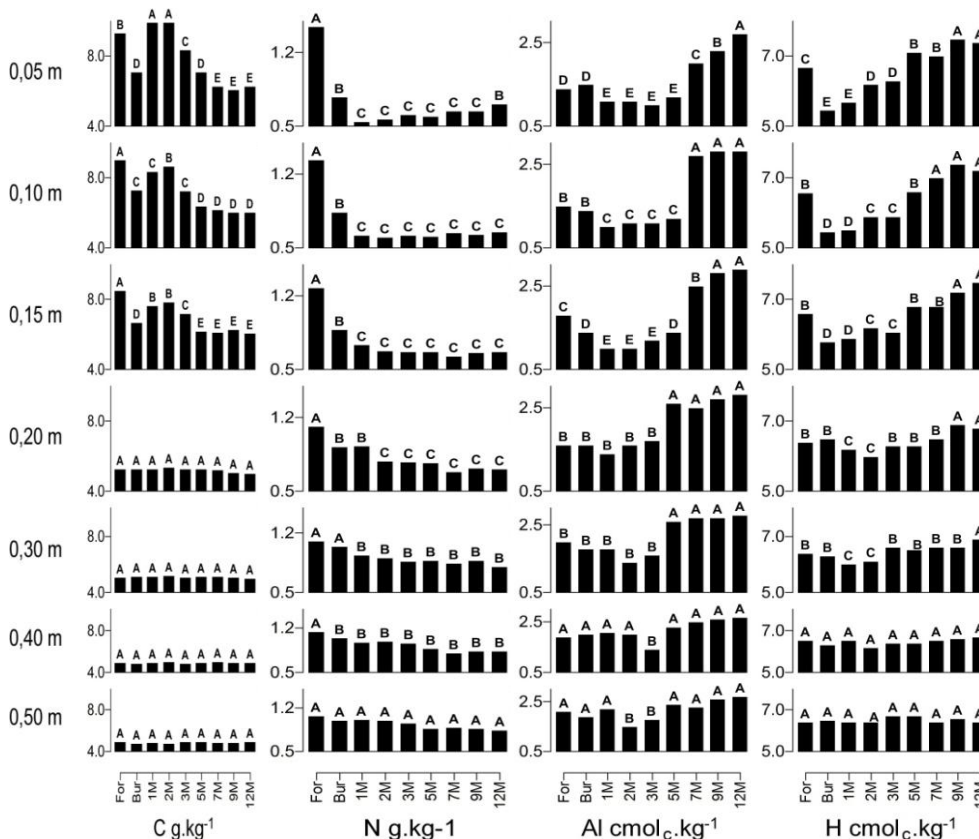
For – Forest before burning, Bur – 16 hours after burning; 1M – 1 month, 2M – 2 months, 3 M – 3 months, 5M – 5 months, 7M – 7 months, 9M – 9 months, and 12M – 12 months after burning.

Figure 4. Mean values of total organic carbon (C), total nitrogen (N), exchangeable aluminum (Al), and exchangeable hydrogen (H) at different depths, sampled at different times. Means followed by the same letter do not differ by Tukey's test ($p < 0.05$).

N values decreased shortly after the burn, especially in the superficial layers, up to the depth of 0.20m. Several studies report the loss of N in the soil by volatilization after vegetation burn (DeBell & Ralston, 1970; Grier, 1975; DeBano, Eberlein, & Dunn, 1979; Raison, Khanna, & Woods, 1985; McGrath, Comerford, & Duryea, 2000a; McGrath, Duryea, Comerford, & Cropper, 2000b; McGrath et al., 2001; Rheinheimer, Santos, Fernandes, Mafra, & Almeida, 2003). Nitrogen losses by volatilization are related to burning of organic matter, which contains significant amounts of N, and can result in losses of 50-90% of the N content stored in the vegetation and soil (Holscher, Moller, Denich, & Folster, 1997; Kauffman, Cummings, & Ward, 1998; Kauffman et al., 1995; Mackensen, Holscher, Klinge, & Folter, 1996). In general, C and N levels are more susceptible to surface changes (Desjardins, Barros, Sarrazin, Girardin, & Mariotti, 2004; McGrath et al., 2001), where physical changes resulting from vegetation removal can increase processes such as erosion, runoff, and leaching.

For the soil acidity components Al^{3+} and H^+, a similar pattern of variation was observed over time, with a reduction in the first months in relation to the values observed before the burn, followed by an increase between the fifth and the seventh months, which persisted until the last period analyzed. As discussed earlier with reference to pH, we can infer that up to five months after the burn, release of organic acids occurred by soil organic matter mineralization, either by the action of fire or by soil microbial activity. Such organic acids may have been involved in complexing these cations and reducing their levels in the soil. These results can be corroborated by the analysis of the content of C, Al^{+3}, and H^+ (Figure 4), wherein the C content increases, while the Al^{+3} content and H^+ content reduce (0.0-0.15 m). Similarly, Numata et al. (2002) also related the increase of Al concentration in the soil to the release of this cation from organic complexes through decomposition of organic matter.

The lack of replacement of the organic material in the soil and the intense microbial activity on the carbon that still existed in the soil may have led to a reduction in the C content of the soil in the third month after the burn. Consequently, Al^{3+} and H^+ that were previously complexed are returned to the soil, favoring the increased availability of these cations. These results demonstrate the great importance of soil organic matter in combating soil acidity in this region. Soils in the Amazon region are considered to have a low nutrient content and acid content, and a low cation exchange capacity (Anjos & Pereira, 2014). Over time, the burning of natural forest vegetation promotes a reduction in the organic C content, directly influencing soil fertility by increasing acidity and nutrient availability.

In the first months, an increase in the values of the sum of bases (SB) and base saturation (V%) was observed up to a depth of 0.20m when compared to the forest soil before the burn (Figure 5). This increase in the base concentration is associated with rapid release by biomass burn (Kauffman et al., 1994). In a study on the nutrient balance in Ultisol (Argissolo Amarelo) soil in the Amazonian rainforest after a burn, Sampaio, Fontes, Costa, and Jucksch (2003) found significant amounts of nutrients, mainly Ca^{2+} and Mg^{2+}, in the ashes. Nevertheless, two months after the forest burn, the values of SB and V% were reduced as a function of evaluation time, with levels lower than before the forest burn. This reduction of the sum of bases may have occurred due to cation losses by erosion and soil leaching, or even due to the absorption of Ca^{2+}, Mg^{2+}, and K^+ by plants that colonized after burning.

The variation in the cation exchange capacity (T) values and aluminum saturation (m%) after the burn in the more superficial layers (0-0.15 m) are consistent with Al^{3+} and H^+ dynamics, which were reduced in the first evaluated periods, followed by an increase that remained up to 12 months. In the Amazon region, soils are generally acidic, with high exchangeable aluminum saturation (m%) (Seubert, Sanchez, & Valverde, 1977; Korning, Thomsen, Dalsgaard, & Nørnberg, 1994; Botschek, Ferraz, Jahnel, & Skowronek, 1996; Brouwer, 1996). High T-value is often largely due to high concentrations of Al^{3+} in soils with low concentrations of basic cations. The high nutrient recycling efficiency observed in Amazonian forests has been correlated with their high biological diversity. Nutrient recycling counteracts soil leaching because it represents a mechanism for conserving nutrients in the ecosystem, while promoting biological productivity and the good nutritional status of plants. The lower concentration of nutrients verified in the area after the burn indicates the importance of vegetation cover for the cycling of nutrients and maintenance of this ecosystem.
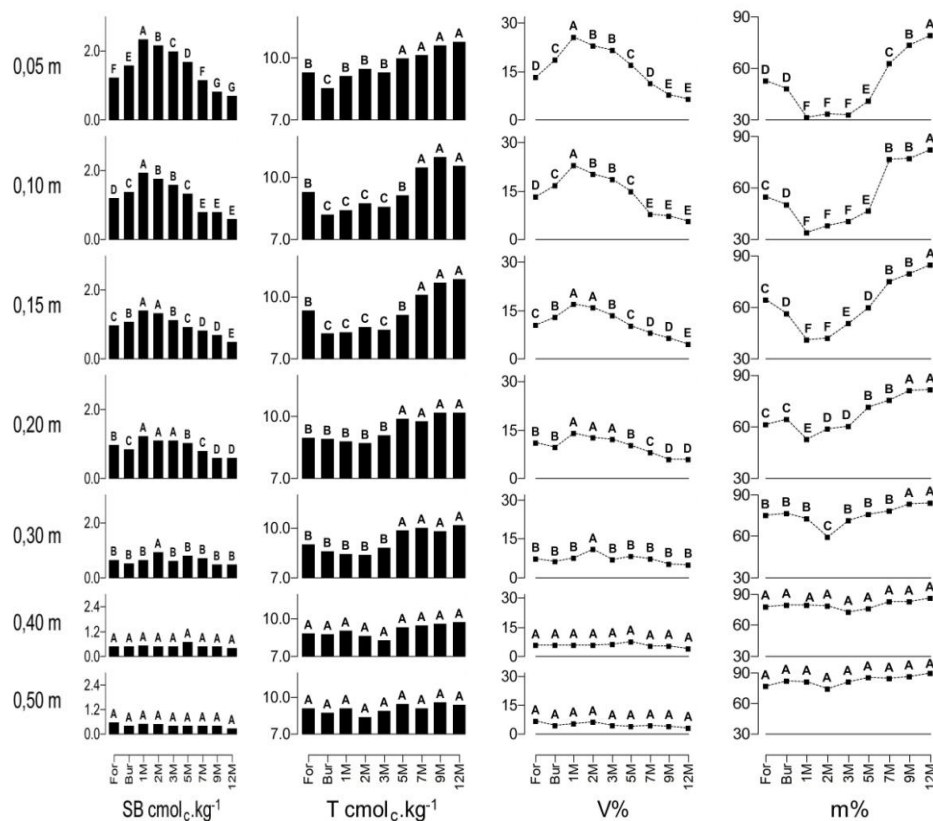
For – Forest before burning, Bur – 16 hours after burning; 1M – 1 month, 2M – 2 months, 3 M – 3 months, 5M – 5 months, 7M – 7 months, 9M – 9 months, and 12M – 12 months after burning.

Figure 5. Means of the sum of bases (SB), cation exchange capacity (T), base saturation (V%), and saturation by aluminum (m%) at different depths, sampled at different times. Means followed by the same letter do not differ by Tukey's test (p < 0.05).

Conclusion

The superficial layers of soil were more sensitive to the fire action. In these layers, the burn caused changes in all the chemical attributes evaluated.

Ashes from vegetation burn increased pH values, basic cations, and C values only in the first months, resulting in higher basal saturation values during this period.

The practice of slash-and-burn after 12 months resulted in lower values of pH, Ca, Mg, K, and P and higher values of Al and H, as well as saturation by aluminum in the soil, indicating this practice contributes to the reduction of soil fertility.

References

Anjos, L. H. C., & Pereira, M. G. (2014). Estado atual do conhecimento dos solos na região amazônica. In P. G. S. Wadt, A. L., Marcolan, S. C. G. Matoso, & M. G. Pereira (Ed.). *Manejo dos solos e a sustentabilidade da produção agrícola na Amazônia Ocidental* (p. 50-65). Porto Velho, RO: SBCS.

Araújo, E. A., Ker, J. C., Mendonça, E. S., Silva, I. R., & Oliveira, E. K. (2011). Impacto da conversão floresta - pastagem nos estoques e na dinâmica do carbono e substâncias húmicas do solo no bioma Amazônico. *Acta Amazonica*, 41(1), 103-114. DOI: 10.1590/S0044-59672011000100012

Bohn, H. L., Mcneal, B. L., & O'connor, G. A. (2001). *Soil Chemistry* (3rd ed.). New York, US: John Wiley & Sons.

Botschek, J., Ferraz, J., Jahnel, M., & Skowronek, A. (1996). Soil chemical properties of a toposequence under primary rain forest in the Itacoatiara vicinity (Amazonas, Brazil). *Geoderma*, 72(1), 19-32. DOI: 10.1016/0016-7061(96)00026-2

Braz, A. M. S., Fernandes, A. R., & Alleoni, L. R. F. (2013). Soil attributes after the conversion from forest to pasture in Amazon. *Land Degradation & Development*, 24(1), 33-38. DOI: 10.1002/ldr.1100

Brouwer L. C. (1996). Nutrient cycling in pristine and logged trop-ical rain forest: a study in Guyana. Tropenbos. Guyana series 1. Utrecht: Utrecht University, Elinkwijk.

Carvalho, J. A., Amaral, S. S., Costa, M. A. M., Soares Neto, T. G., Veras, C. A. G., Costa, F. S., …, Frade, E. F. (2016). CO_2 and CO emission rates from three forest fire controlled experiments in Western Amazonia. *Atmospheric Environment*, *135*(1), 73-83, 2016. DOI: 10.1016/j.atmosenv.2016.03.043

Cerri, C. C., Volkoff, B., & Eduardo, B. P. (1985). Deforestation effect on microbial biomass of a yellow latosol from Amazonic area, Brazil. *Revista Brasileira de Ciência do Solo*, *9*(1), 1-4. DOI: 10.1590/S0044-59672012000100002

Couto, E. G., Klamt , E., & Stein, A. (2000). Estimation of exchangeable potassium and clay content in soils with scattered sampling in southern Mato Grosso, Brazil. *Revista Brasileira de Ciência do Solo*, *24*(1), 129-140. DOI: 10.1590/S0100-06832000000100015

Davidson E. A., Verchot, L. V., Cattanio J. H., Ackerman I. L., & Carvalho J. E. M. (2000). Effects of soil water content on soil respiration in forests and cattle pastures of eastern Amazônia. *Biogeochemistry*, *48*(1), 53-69. DOI: 10.1023/A:1006204113917

Davidson, E. A., Carvalho, C. J. R., Figueira, A. M., Ishida, F. Y., Ometto, J. P. H. B., Nardoto, G. B., … Martinelli, L. A. (2007). Recuperation of nitrogen cycling in Amazonian forests following agricultural abandonment. *Nature*, *447*(7147), 995-998. DOI: 10.1038/nature05900

Dias-Filho, M., Davidson, E. A. & Carvalho, C. (2001). Linking biogeochemical cycles to cattle. Pasture Management and Sustainability in the Amazon Basin. In McClain, M. E., Victoria, R. L., & Richey, J. E. (Ed.), *The Biogeochemistry of the Amazon Basin* (p. 84–105). New York, US: Oxford Univ. Press.

DeBano, L. F., Eberlein, G. E., & Dunn, P. H. (1979). Effects of burning on chaparral soils: I. Soil nitrogen. *Soil Science Society of America Journal*, *43*(1), 504-509. DOI: 10.2136/sssaj1979.03615995004300030015x

DeBell, D. S., & Ralston, C. W. (1970). Release of nitrogen by burning light forest fuels. *Soil Science Society of America Proceedings*, *34*(6), 936-938. DOI: 10.2136/sssaj1970.03615995003400060033x

Desjardins, T., Barros, E., Sarrazin, M., Girardin, C., & Mariotti, A. (2004). Effects of forest conversion to pasture on soil carbon content and dynamics in Brazilian Amazonia. *Agriculture, Ecosystems & Environment*, *103*(2), 365-373. DOI: 10.1016/j.agee.2003.12.008.

Donagema G. K., Campos, D. V. B., Calderano, S. B., Teixeira, W. G., & Viana, J. H. (2011). *Manual de métodos de análises de solos*. Rio de Janeiro, RJ: Embrapa Solos.

Fearnside, P. M., & Barbosa, R. I. (1998). Soil carbon changes from conversion of forest to pasture in Brazilian Amazonia. *Forest Ecology and Management*, *108*(1), 147-166. DOI: 10.1016/S0378-1127(98)00222-9

Fearnside, P. M. (2005). Deforestation in Brazilian Amazonia: History, rates, and consequences, *Conservation Biology*, *19*(3), 680–688.

Ferreira, S. J. F., Luizão, F. J., Miranda, S. A. F., Silva, M. S. R., & Vital, A. R. T. (2006). Nutrientes na solução do solo em floresta de terra firme na Amazônia Central submetida a extração seletiva de madeira. *Acta Amazônica*, *36*(1), 59-68. DOI: 10.1590/S0044-59672006000100008

Galang, M. A., Markewitz, D., & Morris, L. A. (2010). Soil phosphorus transformations under forest burning and laboratory heat treatments. *Geoderma*, *55*(3-4), 401-408. DOI: 10.1016/j.geoderma.2009.12.02

Grier, C. C. (1975). Wildfire effects on nutrient distribution and leaching in a coniferous ecosystem. *Canadian Journal of Forest Research*, *5*(4), 559-607. DOI: 10.1139/x75-087

Holscher, D., Moller, R. F., Denich, M., & Folster, H. (1997). Nutrient imput-output budget of shifting agriculture in Eastern Amazônia. *Nutrient Cycling in Agroecosystems*, *47*(1), 49-57. DOI: 10.1007/BF01985718.

Johnson, C. M., Vieira, I. C. G., Zarin, D. J., Frizano, J., & Johnson, A. H. (2001). Carbon and nutrient storage in primary and secondary forests in eastern Amazonia. *Forest Ecology and Management*, *147*(2), 245-252. DOI: 10.1016/S0378-1127(00)00466-7

Kauffman, D., Cummings, D., & Ward, D. (1994). Relationships of fire, biomass and nutrient dynamics along vegetation gradient in the Brazilian Cerrado. *Journal of Ecology*, *82*(3), 519-531. DOI: 10.2307/2261261

Kauffman, J. B., Cummings, D. L., & Ward, D. E. (1998). Fire in the Brazilian Amazon: 2. Biomass, nutrient pools, and losses in cattle pastures. *Oecologia*, *113*(3), 415-427. DOI: 10.1007/s004420050394

Kauffman, J. B., Cummings, D. L., Ward, D. E., & Babbitt, R. (1995). Fire in the Brazilian Amazon: 1. Biomass, nutrient pools, and losses in slashed primary forest. *Oecologia*, *104*(4), 397- 408. DOI: 10.1007/BF00341336

Korning, J., Thomsen, K., Dalsgaard, K., & Nørnberg, P. (1994). Characters of three Udults and their relevance to the composition and structure of virgin rain forest of Amazonian Equador. *Geoderma*, *63*(2), 145–64. DOI: 10.1016/0016-7061(94)90003-5

Laurance, W. F., Cochrane, M. A., Bergen, S., Fearnside, P. M., Delamônica, P., Barber, C., D'Angelo, S., & Fernandes, T. (2001). The future of the Brazilian Amazon. *Science*, *291*(5543), 438–439. DOI: 10.1126/science.291.5503.438

Longo, R. M., & Espíndola, C. R. (2000). Alterações em características químicas de solos da região Amazônica pela introdução de pastagens. *Acta Amazônica*, *30*(1), 71-80. DOI: 10.1590/1809-43922000301080

Mackensen, J., Holscher, D., Klinge, R., & Folter, H. (1996). Nutrient transfer to the atmosphere by burning of debris in eastern Amazonia. *Forest Ecology and Management*, *86*(1-3), 121-128. DOI: 10.1016/S0378-1127(96)03790-5

Markewitz, D., Davidson, E. A., Moutinho, P., & Nepstad, D. C. (2004). Nutrient loss and redistribution after forest clearing on a highly weathered soil in Amazonia. *Ecological Applications*, *14*(4), 177–199. DOI: 10.1890/01-6016

McGrath, D., Comerford, N., & Duryea, M. (2000a). Litter dynamics and monthly fluctuations in soil phosphorus availability in an Amazonian agroforest. *Forest Ecology and Management*, *131*(1-3), 167-184. DOI: 10.1016/S0378-1127(99)00207-8

McGrath, D., Duryea, M. L., Comerford, N. B., & Cropper, W. P. (2000b). Nitrogen and phosphorus cycling in an Amazonian agroforest nine years following forest conversion. *Ecological Applications*, *10*(6), 1633-1647. DOI: 10.1890/1051-0761(2000)010[1633:NAPCIA]2.0.CO;2

McGrath, D. A., Smith, C. K., Gholz, H. L., & Oliveira, F. D. (2001). Effects of land-use change on soil nutrient dynamics in Amazonia. *Ecosystems*, *4*(7), 625-645. DOI: 10.1007/s10021-001-0033-0

Medeiros, I. M. S., Lima, S. G., Maffi, B. A., Abadia, L. L., Martins, F. A., Dalamaria, T., & Ramalho, A. A. (2015). Inadequacies in good manufacturing practices and high health risks are still problems in food production in public preschools and daycares in Rio Branco, Acre, Western Brazilian Amazonia. *Advances in Food Technology and Nutrition Sciences*, *SE*(1), 38-46. DOI: 10.17140/AFTNSOJ-SE-1-106

Morton, D. C., Defries, R. S., Randerson, J. T., Giglio, L., Schroeder, W., & van der Werf, G. R. (2008). Agricultural intensification increases deforestation fire activity in Amazonia. *Global Change Biology*, *14*(10), 2262-2275.

Numata, I., Soares, J. V., & Leonidas, F. C. (2002). Comparison of fertility of soils in Rondônia with different times of conversion of forest to pasture. *Revista Brasileira de Ciência do Solo*, *26*(4), 949–955. DOI: 10.1590/S0100-06832002000400012

Orrutéa, A. G., Melo, V. F., Motta, A. C. V., & Lima, V. C. (2012) Mineralogia e reserva de K de Cambissolos submetidos a diferentes manejos após derrubada e queima da floresta na Amazônia Meridional. *Acta Amazônica*, *42*(4), 461-70. DOI: 10.1590/S0044-59672012000400003

Pedroso Junior, N. N., Murrieta, R. S. S., & Adams, C. A. (2008). Agricultura de corte e queima: um sistema em transformação. *B. M. P. E. G. Ciências Humanas*, *3*(2), 3-12. DOI: 10.1590/S1981-81222008000200003

Raison, R. J., Khanna, P. K., & Woods, P. V. (1985). Mechanisms of element transfer to the atmosphere during vegetation fires. *Canadian Journal of Forest Research*, *15*(1), 132-140. DOI: 10.1139/x85-022

Rheinheimer, D. S., Santos, J. C. P., Fernandes, V. B. B., Mafra, A. L., & Almeida, J. A. (2003). Modificações nos atributos químicos de solo sob campo nativo submetido à queima. *Ciência Rural*, *33*(1), 49-55. DOI: 10.1590/S0103-84782003000100008

Sampaio, F. A. R., Fontes, L. E. F., Costa, L. M., & Jucksch, I. (2003). Nutrient and phytomass dynamics in a yellow argissol under amazonian tropical forest after burning and rice cultivation. *Revista Brasileira de Ciência do Solo*, *27*(6), 1161- 1170. DOI: 10.1590/S0100-06832003000600020

Sanchez, P. A., Bandy, D. E., Villachica, J. H., & Nicholaides, J. J. (1982). Amazon Basin soils: management for continuous crop production. *Science*, *216*(4548), 821-827. DOI: 10.1126/science.216.4548.821

Santos, H. G., Jacomine, P. K. T., Anjos, L. H. C., Oliveira, V. A., Lumbreras, J. F., Coelho, M. R., Almeida, J. A., Cunha, T. J. F., & Oliveira, J. B. (2013). *Sistema brasileiro de classificação de solos*. Brasília, DF: Embrapa Solos.

Seubert, C. E., Sanchez, P. A., & Valverde, C. (1977). Effect of land clearing methods on soil properties and crop performance in an Ultisol of the Amazon jungle of Peru. *Tropical Agriculture*, *54*(4), 307-21.

Silva, G. R., Silva, M. L. Jr., & Melo, V. S. (2006). Effect of land use and management on chemical properties of a yellow latosol in Pará State, Brazil. *Acta Amazonica*, *36*(2), 151-158. DOI: 10.1590/S0044-59672006000200004

Tedesco, M. J., Gianello, C., Bissani, C. A., Bohnen, H., & Volkweiss, S. J. (1995). *Análise de solo, plantas e outros materiais*. Porto Alegre, RS: UFRGS.

Vitousek, P. M. (1984). Litterfall, nutrient cycling, and nutrient limitations in tropical forests. *Ecology*, *65*(1), 285-298. DOI: 10.2307/1939481

Yeomans, J. C., & Bremner, J. M. (1998). A rapid and precise method for routine determination of organic carbon in soil. *Journal Communications in Soil Science and Plant Analysis*, *19*(13), 1467-1476. DOI: 10.1080/00103628809368027

Zarin, D. J., Davidson, E. A., Brondizio, E. S., Vieira, I. C. G., SÁ, T., Feldpausch, T., Schuur, E. A. G., ... Denich, M. (2005). Legacy of fire slows carbon accumulation in Amazonian forest regrowth. *Frontiers in Ecology and Environment*, *3*(7), 365-369. DOI: 10.1890/1540-9295(2005)003[0365:LOFSCA]2.0.CO;2