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Effects of Burning on Chemical Attributes And Soil Organic Matter In Cerrado Areas

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***Abstract*— *The practice of burning for soil management is common due to its low cost and simplicity, allowing immediate soil reuse. Despite its benefits, such as stimulating pasture regrowth and pest control, there are negative effects, such as soil degradation and reduced productivity in the long term. The technique is controversial, balancing tradition and sustainability, requiring effective alternatives without compromising environmental health. Research indicates both improvements in fertility and damage to soil properties, indicating the need for responsible use. This study evaluated the immediate effect of fire on the chemical attributes of pasture soil, comparing it with a soil of adjacent native vegetation. Conducted at Chácara Vitória, in Monte do Carmo - TO, the experiment Cerrado. analyzed two areas: one of virgin cerrado and another of pasture that had been burned annually for over twenty years. Laboratory analysis showed an increase in K, S, Mn, Zn, P-meh, Mg, Fe, Cu and Ca, and a decrease in Al, B, H+Al. The reviewed literature presents diverse results due to several variables. It is concluded that burning significantly impacts the chemical composition of the soil and should be carefully evaluated considering its long-term implications.*

I. INTRODUCTION

The frequent cultural practice of soil management through burning is an empirical technique and considered low cost, as it does not require a large amount of labor or heavy machinery. In addition, it is a simple approach, allowing immediate reuse of the soil. Burning is mainly used to clear and prepare the land before planting, as well as to renew pastures and control pests and diseases (Redin et al., 2011). The practice of controlled burning, although a contentious issue, is a classic example of the dilemma between tradition and sustainability. Spera et al. (2000) highlight the negative effects of this practice, such as soil sterilization and degradation. However, Rheinheimer et al. (2003) recognize its common use in the central-western and northern regions of Brazil, where it is valued for stimulating vigorous regrowth of pastures. Post-winter burning, supported by Behling and Pillar (2007), may be effective against shrub invasion, but Dick et al. (2008) and Heringer et al. (2002) warn of long-term damage, such as deterioration of soil chemical properties and reduced productivity.

This duality reflects the complexity of balancing traditional empirical agricultural methods with modern techniques, which is increasingly growing and in order to meet the needs of environmental preservation. The search for sustainable alternatives that maintain the effectiveness of pasture management without compromising the health of the ecosystem is an ongoing challenge for researchers and farmers.

Fire can directly and indirectly alter the chemical, physical and biological characteristics of the soil. Many experts have studied the effects of burning on the soil and warn of points with positive and negative results, in statements by (De Bano, 1989; Spera et al., 2000; Certini, 2005; Inbar et al., 2014), however, no study actually defines what are the greatest relevance to the use of this management, whether it is in fact viable or not. It depends on the circumstances present in each scenario. Gorng et al (2013) observed in research that degraded soils with characteristics of Latosols have the capacity to restore their chemical elements after this conservation process. Combustion can cause changes in the chemical reaction of the soil, inducing acidity, causing an increase in pH, due to the release of elements such as mainly high potassium content during the burning of organic components. Burning can result in a notable increase in bases such as Potassium (K) and calcium (Ca).

According to studies by Melo et al. (2014), burning can induce changes in the configuration of the soil, particularly in the outer layers, as a result of exposure to high temperatures. This process can lead to a reduction in soil porosity, interfering with the capacity to absorb water and ventilate the air in the subsoil. Burning can result in greater compaction of the soil due to the reduction of organic matter and the compromise of its structure. Soil texture is also subject to changes after burning, which can result in the formation of more rigid layers or crusts on the surface of the soil. Regarding soil biology, the practice of burning can lead to the elimination of vital microorganisms such as bacteria, fungi and actinomycetes essential for the decomposition of organic compounds and for the nutrient cycle, as described by Thakur et al. (2013).

According to Embrapa (2019), the practice of controlled burning in the agricultural context, when carried out with precision and under specialized supervision, can be a valuable tool for effective soil management. This process can provide the transformation of organic matter into other nutrients such as potassium (K), calcium (Ca), phosphorus (P), magnesium (Mg), nitrogen (N) among others, and increase the level (hydrogen potential) of the soil pH. However, the ashes can have harmful effects on the soil and water depending on the degree of quantitative mass per dcm³, they act in the eradication of insects, weed seeds and partial destruction of inoculums of harmful pests lodged in the soil that harm crops.

With careful implementation and monitoring by professionals in the field, this technique can improve soil fertility and promote a balanced agricultural ecosystem. These actions, when aligned with the principles of sustainability, are essential for maintaining agricultural productivity and preserving the biodiversity of local ecosystems. It is essential that such practices are carried out responsibly, aiming for a balance between agricultural production and environmental health, according to (Araújo et al., 2005).

Studies that involve understanding the changes that occur in the soil after the action of burning are of great importance. Evaluating the quality of the soil after the fire, considering its physical, chemical and microbiological attributes and comparing it with an area that did not undergo such a process can help in the control.

II. METODOLOGY

This is an experimental study, carried out in the field using soil collection. The experiment was carried out at Chácara Vitória, located in the Muleque Settlement, in the municipality of Monte do Carmo - TO, located at Latitude 10°33'29.0"S and Longitude 48°15'05.7"W, in the center of the state of Tocantins, as shown in the map shown in Fig. 1

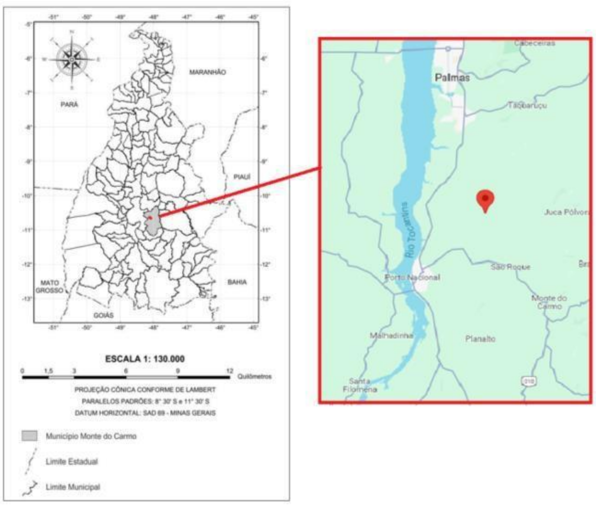

Fig. 1 - Geographical location of the study site
Source: Adapted from Medeiros and Caríba (2014) and Google Maps (2024)

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The municipality of Monte do Carmo – TO has geological environments that include terrains of the Parnaíba Sedimentary Basin, Metamorphic Complexes of the Archean and Lower Proterozoic, Cenozoic Covers and Fold Belts of the Middle and Upper Proterozoic. Geomorphologically, it presents structural forms with tabular surfaces and structural platforms; erosive forms, with erosive tabular surfaces, pediplane surfaces, inselbergs and fluvial terraces; and types of dissection in ridges, tables, tabular interfluves, ravines and hills, among other types of dissection (SEPLAN, 2008), which make up the Dissected Plateau of Tocantins. The soils of the region are classified as Latosols, Litholic Neosols and Plinthosols (SEPLAN, 2012).

The climate of the municipality is classified as C2wA'a'' - humid subhumid climate with moderate water deficit, with an average annual precipitation of approximately 1700 mm and an average annual temperature between 26 and 27°C, according to the Thornthwaite Method. Vegetationally, the municipality is located in the Ecological Tension Region

(Cerrado/Seasonal Forest Enclave), where different types of vegetation from various phytoecological regions compete for the same environment, creating areas of ecological tension. When two subtypes of vegetation from different phytoecological regions do not mix, enclaves or vegetation mosaics are formed. In dissected hilly terrains, this tension manifests itself with the forest occupying the valleys and lower slopes, while the cerrado formations occupy the tops and upper slopes (SEPLAN, 2012).

For data collection, two nearby areas were selected, one in virgin cerrado without burning, and the other a pasture area, adjacent to the first area of virgin cerrado, with annual burning management in more than twenty (20) years of opening, both with the same soil characteristics, without ever having been limed or any chemical fertilization. Measuring both areas 200x200 (40,000m²/4ha), located in Chácara Vitória, Córrego Fundo Monte do Carmo /TO.

The environments are representative of the region, consisting of pastures commonly used for extensive cattle raising and an area with soil under native vegetation. The soil in the study area belongs to the Latosol class, with a predominantly flat relief.

Five (5) sampling points were collected from each area at a depth of 0 to 20 cm. These were homogenized and became a single sample for each area. After collection, the samples were sent for analysis by the MB Agronegócios Laboratory, in order to identify the chemical characteristics of each soil. The methodology used to determine the parameters was not reported, considering that it is a private laboratory, where the analysis is performed and the report is provided.

The analyses were studied to verify the difference in chemical parameters for each type of sample, comparing the area subjected to burning with the virgin cerrado area.

III. RESULTS AND DISCUSSIONS

Through the chemical analysis carried out, the chemical parameters of each soil sample were found. These are presented in Table 1 for virgin soil.

Table.1 - Result of the soil analysis report for the Cerrado Virgem/Reserva

PARÂMETROS ESTRATÉGICOS INDICADORES DA FERTILIDADE

CTC Potencial (T) 7,78 cmol/dcm³	pH CaCl2 4,80	Sat. Al (m) 3,15% Ca/CTC 25,32 %
Soma de bases (S) 3,08 cmol/dcm³	pH H2O nr	Mat. Or. 3,06% Mg/CTC 13,36 %
Sat. por bases (V) 39,59 %	pH SMP 5,88	Carbono nr g/dm³ K/CTC 0,89 %

TEORES QUÍMICOS DOS ELEMENTOS

MACRONUTRIENTES						EL LIM.		MICRONUTRIENTES						
Ca	Mg	K	P-meh	K	S	H+Al	Al	Fe	Mn	Zn	Cu	B	Mo	Co
1,97	1,04	0,07	3,10	26,58	1,69	4,70	0,10	45,75	12,70	0,86	0,44	0,10	nr	Nr
	cmol/dm³			mg/dm³		cmol/dm³					mg/dm³			
REFERÊNCIAS TÉCNICAS														
3,89	1,56	0,39	30,10	152,49	10,00	1,94	0,10	31,00	9,00	1,60	1,30	0,60	0,0	0,0
PERCENTUAL DE ATIGIMENTO ATUAL														
51%	67%	17%	10%	17%	17%	242%	100%	148%	141%	54%	34%	17%	0,0%	0,0%

Report Source: MB Agronegócios/Laboratory No. 62072-2024

The results of the report indicate a significant concentration of limiting hydrogen (H), Aluminum (Al), Iron (Fe), Calcium (Ca), Magnesium (Mg) and Potential CTC. The micronutrients Mo and Co were not detected present in the analysis.

Regarding soil subjected to burning, the data are presented in Table 2.

Table.2 Result of the soil analysis report with Fire Action

PARÂMETROS ESTRATÉGICOS INDICADORES DA FERTILIDADE														
CTC Potencial (T) 7,40	cmol/dcm³	pH CaCl2	5,85	Sat. Al (m) 0,00 %	Ca/CTC 37,29 %									
Soma de bases (S) 5,40	cmol/dcm³	pH H2O	nr	Mat. Or. 1,83 %	Mg/CTC 23,91 %									
Sat. por bases (V) 72,98	%	pH SMP	6,69	Carbono nr g/dm³	K/CTC 11,75 %									
TEORES QUÍMICOS DOS ELEMENTOS														
MACRONUTRIENTES						EL LIM.		MICRONUTRIENTES						
Ca	Mg	K	P-meh	K	S	H+Al	Al	Fe	Mn	Zn	Cu	B	Mo	Co
2,76	1,77	0,87	81,00	339,00	11,43	2,00	0,00	77,56	76,65	2,39	0,62	0,07	nr	nr
cmol/dm³			mg/dm³			cmol/dm³		mg/dm³						
REFERÊNCIAS TÉCNICAS														
3,70	1,48	0,37	20,10	144,67	10,00	1,85	0,10	31,00	9,00	1,60	1,30	0,60	0,0	0,0
PERCENTUAL DE ATINGIMENTO ATUAL														
75%	120%	235%	403%	235%	114%	108%	0,0%	250%	852%	149%	48%	12%	0,0%	0,0%

Report Source: MB Agronegócios/Laboratory No. 62072-2024

When comparing the results presented in the report in Table 2 (with fire) with Table 1 (virgin soil), an increase in the hydrogen potential (pH) in the macro and micro nutrients and a sudden decrease in H+Al can be seen. A significant increase in high chemical elements is observed, being:

- Remaining Phosphorus (P-meh) went from 3.10 in virgin soil to 81.00 in soil subjected to burning, which represents an increase of 2,512.90%;
- Potassium (K) went from 26.58 in virgin soil to 339.00 in burned soil, an increase of 1,175.39%;
- Sulfur (S) went from 1.69 to 11.43, representing a 576.33% increase;
- Manganese (Mn) was 12.70 in virgin soil and 76.65 in soil affected by fire, which represents an increase of 503.54%;
- Zinc (Zn) went from 0.86 to 2.39; an increase of 177.90%;
- Magnesium (Mg) went from 1.04 to 1.77, an increase of 70.19%;
- Iron (Fe) went from 45.75 to 77.56, representing a 69.53% increase;
- Copper (Cu) went from 0.44 to 0.62; indicating a 40.90% increase;
- Calcium (Ca) levels increased from 1.97 in virgin soil to 2.76 in soil subjected to burning, which represents an increase of 40.10%.

On the other hand, some micronutrients showed a decrease in soil subjected to burning in relation to virgin soil, where:

- Aluminum (Al) went from 10.00 to 0.00, which represents a 100% reduction in value;
- The Potential Acidity of the soil (H+Al) went from 4.70 to 2.00, representing a 57.45%

  decrease in the content;
- Boron (B) went from 0.10 to 0.07, representing a 30% reduction in content.

In general, according to the expert reports, there were distinct significances between chemical nutrients that underwent transformations over more than twenty (20) years of pasture with fire management. When considering soil properties, it is necessary to consider chemical, physical and biological properties, and a small change in any of these can affect the entire soil dynamics (Santos; Bahia; Teixeira, 1992).

Repeated and intense fires impoverish the soil, degrading almost all organic matter and gradually reducing nutrient stocks, without allowing their regeneration (Soares, 1995). Soon after the fire, there is an increase in the availability of complex nutrients for plants, such as nitrogen, phosphorus, potassium, sodium, calcium and magnesium due to the accumulation of ash on the soil surface (Soares, 1995; Gatto et al., 2003; Rheinheimer et al., 2003; Knicker, 2007).

Ash also affects soil acidity, as burning reduces the amount of exchangeable aluminum in Cerrado soils, raises pH and increases the concentration of bases (Ulery; Graham, 1993). However, this effect of ash on pH is temporary and the increase is usually noticed more immediately, including for other nutrients, tending to decrease over time and even disappear due to leaching, which can result in even lower concentrations when compared to soils that have not been burned (Knicker, 2007).

In the study carried out by Franz (2022), on the influence of burning on cerrado soil, in the 0 to 2.5 cm layer, an increase in pH values was observed, which made the soil less acidic. Exchangeable calcium (Ca) had a significant increase from 0 to 5 cm in one area and 2.5 to 20 cm in another; exchangeable potassium (K) increased in the 0 to 2.5 cm layer; sulfur (S) increased up to the 5 cm layer and decreased its concentration significantly from 10 to 20 cm; zinc (Zn) showed an increase in layers from 5 to 10 cm; the concentration of copper (Cu) increased in the areas affected by fire in the 0 to 5 cm layer and normalized after 2 months of burning; boron (B) had an increase from 0 to 2.5 cm in one studied area, and a decrease from 5 to 10 cm; sulfur (S) increased significantly in the layers from 0 to 5 cm, from 5 to 10 cm there was no difference and from 10 to 20 cm there was a significant decrease; manganese (Mn) showed an increase in only one area in the layer from 5 to 10 cm.

On the other hand, in the aforementioned study, Franz (2022) observed a reduction in iron (Fe) concentrations in the layers from 2.5 to 5 cm in one area, from 10 to 20 cm in another area and in all plots in another area; there was also a decrease in the concentrations of extractable hydrogen (H) and exchangeable aluminum (Al) in the most superficial layer of the soil, from 0 to 2.5 cm in one area and from 2.5 to 20 cm in another area; while the concentration of exchangeable magnesium (Mg) and total nitrogen (N) did not show a significant change in any area.

Despite the reduction of Al and H, and an increase in pH, the soil in the study by Franz (2022) still presents the same classification in terms of acidity. For Ribeiro and Walter (2008), this is due to the fact that cerrado soils normally present very high levels of Al, low pH values and a lack of nutrients such as N and P, being considered strongly or moderately acidic.

In the present study, unlike that observed by Franz (2022), there was an increase in Mg, N and Fe and a reduction in B. It is similar in terms of the increase in S, Cu, Mn, K and Zn and the decrease in H and Al.

It is worth noting that the effects of fire on the soil are variable in their properties and can change depending on the characteristics of the soil, the relief of the region, the biome, as well as the intensity and duration of the fire. Thus, the differences that occur in a given location may be different from those that occur in others (Knicker, 2007; Swanson, 1981).

Girona-García et al. (2018) observed a 52% and 44% decrease in N concentrations in the surface layer of the soil (0 to 1 cm) after burning, which can be attributed to the combustion of soil organic matter (SOM), which only occurs when temperatures reach between 200 and 250 °C. This is also observed by Franz (2022) previously cited. On the other hand, other authors such as Alcañiz et al., 2016 and San Emeterio et al., 2016 point to a reduction of N in the soil subjected to burning.

Thus, the impacts of induced fire on soil N are quite variable and controversial, which can be explained by differences in vegetation characteristics, soil properties and fire intensity (Wang et al., 2012; AkburaK et al., 2018).

In a study conducted by Sampaio et al. (2003), it was observed that the burning process consumed 36.3% of the initial biomass, resulting in the production of 5.5 Mg ha-1 of ash, which contained significant amounts of nutrients, especially Ca, Mg and K. In the final balance, the area that was burned without cultivation presented a greater loss of nutrients compared to the burned and cultivated area, highlighting the importance of soil cover for the retention of elements in the system. At the end of the rice crop cycle, it was found that the ash still had a residual effect on the system, evidenced by the levels of P, K, Ca and Mg that were higher than those of the control.

As in the present study, the increase in Cu concentration was reported by Stankov Jovanovic et al. (2011). However, Gómez-Rey et al. (2013) noted a marked reduction in the concentration of available Cu in the burned soil, indicating rapid losses of this element, possibly due to erosion after the first rains following the fire.

In the study conducted by Akaburak et al. (2018), the levels of exchangeable cations (Ca, Mg, K, Na, Mn) remained practically the same in the burned and unburned plots, without presenting statistically significant variations or temporal changes due to fire. In contrast, the research by Scharenbroch et al. (2012) identified an increase in the availability of Ca, Mg, K and Na for plants after burning, as in the present study.

According to DeBano (1989), during a fire large amounts of nitrogen, sulfur and phosphorus can volatilize, depending on environmental conditions, as well as the characteristics of the soil and the fire itself.

Shakesby et al. (2015) observed that soil extractable K concentrations were higher one year after burning compared to the pre-fire period. On the other hand, Oliveira-Filho et al. (2018) reported that macronutrient concentrations (Ca, Mg, K and P) in burned and unburned soils were very similar over the one-year study period.

In a study carried out by Simon et al. (2016), investigating the chemical attributes of cerrado soil after burning, it was found that there was no interaction depending on the burning and depth for the nutrients K, Al, Ca, Mg and the Ca+Mg, H+Al, MO, CO ratios.

When analyzing chemical changes in a burned soil in a native area, Rheinheimer et al. (2003) found that K levels in the soil where vegetation had been burned were significantly higher than in unburned areas, confirming the data of Oliveira and Silva (1994) in their study carried out in a burned sugarcane cultivation area, where an increase in K levels was observed in the surface layer of the soil. However, Mendonza et al. (2000) point out that, although there is an initial increase in K due to burning, this nutrient is eventually leached over time, resulting in soil impoverishment. Furthermore, the greater availability of K in burned soil is attributed to mineralization that occurred after burning.

In the present study, there was a significant increase in potassium (K) in the soil with burning, reaching more than 1,175%. This corroborates some of the aforementioned authors, but clashes with some other authors, especially with regard to leaching, since no research was carried out over time to confirm this.

In a study conducted by Alcañiz et al. (2014), an increase in phosphorus (P) concentration was recorded after the fire, however, one year after the burning, the values were lower than those observed before the fire. These results corroborate Certini's (2005) statement that the increase in phosphorus content is temporary and lasts for less than a year.

The transient increase in phosphorus can be attributed to the fact that, during burning, part of the organic phosphorus is converted into inorganic phosphorus (Galang; Markewitz; Morris, 2010), which becomes detectable in soil analyses. However, over time, phosphorus is adsorbed by iron and aluminum oxides, which are abundant in Cerrado soils, remaining retained in the solid fraction of the soil and once again unavailable to plants, no longer being detected in the analyses performed. This process is similar to the behavior of phosphorus supplied through fertilization (Leite et al., 2016).

In the study by Simon et al. (2016), an increase in aluminum was observed in the surface layer of the soil, corroborating what was stated by Jacques (2003), who argues that the action of fire leads to an increase in Al levels and saturation (m%), as well as greater potential soil acidity.

The data from the study carried out in this research in Monte do Carmo – TO showed, differently, a reduction in Al, as well as a decrease in soil acidity. And although it differs from other authors, it is necessary to understand and investigate other chemical elements, in addition to physical and biological elements, to scientifically understand the difference found and justify it.

Regarding pH, a small increase was observed in the soil subjected to burning, however this is not significant, considering that the soil remains considered acidic. Some researchers, such as Franco-Vizcaíno and Sous-Ramirez (1997), argue that the differences in pH values between burned and unburned areas are not significant. Similarly,

Hueso-González, Martínez-Murillo and Ruiz-Sinoga (2018) did not observe significant changes in soil pH after the application of prescribed fire, with the pH remaining stable throughout the five years of the experiment. This suggests that the fire did not have a lasting impact on soil pH, possibly due to the low intensity of the fire.

Fonseca et al. (2017) observed that pH values were significantly higher 2 and 6 months after the burn compared to pre-fire levels at all depths analyzed, including the deepest layers (up to 20 cm). However, after 36 months, pH values returned to levels similar to those recorded before the burn, indicating that the effects of the fire on the soil had disappeared. pH variations may not be significant in fire-affected areas for several reasons. First, soil pH may be restored to its original pH before the fire, with the time required for this recovery varying. Samples were collected two months after the fire, which may influence the detection of changes. In addition, low fire intensity, although not assessed in this study, may be a contributing factor. It is also important to note that the severity of forest fires is directly linked to the amount of combustible material available. For example, the Cerrado has approximately 25 Mg ha-1 of combustible biomass, a value considered low when compared to Brazilian tropical ecosystems such as the Caatinga (74 Mg ha-1) and the Amazon Rainforest (435 Mg ha-1) (Castro; Kauffman, 1998).

Fire can temporarily neutralize soil, reducing its acidity and the levels of aluminum and organic acids. In addition, it can increase the concentration of elements such as calcium, magnesium and potassium on the soil surface due to the oxidation of the ignited organic matter and the incorporation of ash, which contains carbonates, oxides and basic cations such as potassium and sodium (Certini, 2005; Akaburak et al., 2018).

Thus, it can be seen that there is no pattern regarding the effects of fire on soil chemical attributes. Comparing with previous studies, it is possible to observe similarities and differences. Some authors reported an increase in several surface nutrients after burning, but also identified significant decreases in iron and aluminum at certain depths, which is consistent with this study. However, other authors identified an increase in these same nutrients.

The impact of fire on soil acidity also varied. Despite a small increase in pH observed in this study, the soil remained acidic. This behavior is consistent with some research showing that the effects of fire on soil pH are temporary and vary depending on the intensity and frequency of burning.

Additionally, the reduction of exchangeable aluminum and potential acidity (H+Al) after burning is a relevant finding, indicating that fire can temporarily neutralize the soil, increasing the availability of certain nutrients. However, soil recovery and stability after fire are complex and long-term processes, requiring continuous monitoring to understand the dynamics involved.

IV. CONCLUSION

The results of this study demonstrate that soil burning in Monte do Carmo - TO caused significant changes in the chemical composition of the soil when compared to virgin soil. A significant increase in the levels of several nutrients was observed, including phosphorus, potassium, sulfur, manganese, zinc, magnesium, iron, copper and calcium. Phosphorus, for example, showed an impressive increase of 2,512.90%, while potassium increased by 1,175.39%. In contrast, there was a reduction in the levels of aluminum, potential acidity (H+Al) and boron.

These changes reflect the complexity and variability of fire impacts on soil properties, which can be influenced by a variety of factors such as soil type, topography, biome, fire intensity and duration. The literature reviewed suggests that while some nutrients increase temporarily due to mineralization and ash deposition, others may be volatilized or leached, resulting in a decrease over time. For example, initial increases in phosphorus and potassium may be followed by a decrease due to adsorption and leaching, respectively.

In conclusion, this study confirms that burning has a significant and variable impact on soil chemistry. Fire management practices should be carefully evaluated considering their long-term implications for soil fertility and ecosystem balance. A detailed understanding of soil chemical, physical and biological changes following fires is crucial to developing sustainable management strategies that mitigate negative effects and take advantage of the temporary benefits of increased nutrient availability.

Based on the data presented, it is suggested that longitudinal studies be carried out to monitor changes in soil chemical properties over time after burning in order to understand the dynamics of nutrient leaching and adsorption. Furthermore, detailed investigations into the interactions between soil chemical, physical and biological properties are essential to fully understand the impacts of different fire intensities and frequencies.

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