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Investigation of Post-Fire Peatland Natural Recovery, South Kalimantan, Indonesia

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ABSTRACT

Peatlands play a critical role in global habitats since are composed of heterogeneous materials and chemical reactions. Peatland fires significantly change the chemical characteristics of its soil, such as carbon (C), nitrogen (N), phosphorus (P) and potassium (K) content. This study aimed to measure peatland recovery only on those soil chemical characteristics based on two different times of sampling that are five years (Yr+5) and seven years (Yr+7) after the fires in 2015 (taken in 2020 and 2022). This study was conducted in the Balangan River - Batangalai River peat hydrological unit, South Kalimantan, Indonesia. Soil samples were collected at nine different locations, including are six locations in the areas that experienced fires in 2015 and three locations in the areas that did not experience fires. Those soil samples were taken with excavated pits at each sample location at each depth of 10, 20, 30, 40 and 50 cm. This study found that the carbon content in the post-fire area increased by 22.00% and in the natural area by 9.90%. The nitrogen content in the post-fire area increased by 1.94% and in the natural area by 1.17%. The potassium content in the post-fire areas increased by 16.33% and in the natural areas by 4.44%. The phosphorus content in the post-fire area increased by 3.18% and in the natural area by 5.11%. C/N ratio increased by 19.68% and C/P ratio increased by 18.24%. Overall, the increase in carbon, nitrogen, potassium, phosphorus, C/N ratio and C/P ratio in post-fire and natural peatlands indicates an improved condition. This study can provide supporting information for the regulator, management or expertise of the land and forest rehabilitation to speed up the recovery process.

Keywords: peatland, post fire, soil chemical characteristics, carbon, nitrogen.

INTRODUCTION

Peatlands play a critical role in global habitats (IUCN 2017, Williams-Mounsey *et al.* 2021). Peatlands are composed of heterogeneous materials and reactions of nitrification, denitrification, sulphate reduction, oxidation of reduced inorganic sulphides, etc. In peatland processes, sulphate reduction occurs due to changes in Eh and pH, the formation of alkanes, C transformation, mobility and the reduction of N, P and C (Porowski *et al.* 2019). Peatlands, based on geospatial data, cover approximately 423 million ha or 2.84% of the global land area (Xu *et al.* 2018, Anda *et al.* 2021, Yuwati *et al.* 2021). The largest peatland area is located in Southeast Asia, totalling 25 million ha, most of which is in Indonesia (Kiely *et al.* 2021, Atkinson and Alibašić 2023). In total, peatlands in Indonesia cover an area of 13.43 million ha, spread across Sumatra 5.85; Kalimantan 4.54; Papua 3.01 and Sulawesi 0.024 million ha (Anda *et al.* 2021). More than 80% of peatlands in

Southeast Asia are degraded (Mishra *et al.* 2021) and peatlands in Indonesia in 2015 experienced fires covering 2.6 million ha and in 2019 covering 1.65 million ha (Saharjo and Novita 2022). Peatland degradation is largely caused by deforestation, agriculture, plantations, housing and fires (Harrison *et al.* 2020, Uning *et al.* 2020, Ramdzan *et al.* 2022). Post-fire peatland degradation resulted in reduced of carbon stocks (Humpenöder *et al.* 2020, Deshmukh *et al.* 2021, Nelson *et al.* 2021); carbon emissions (Tarigan *et al.* 2021, Mishra *et al.* 2021, Liu *et al.* 2022) changes in the hydrological system (Dohong *et al.* 2018, Šimanauskienė *et al.* 2019, Ingram *et al.* 2019), reduced biodiversity (Wasis *et al.* 2019, Syaufina and Hamzah 2021); health risks (Uda *et al.* 2019, Siregar *et al.* 2022, Santika *et al.* 2023) and economy (Tarigan *et al.* 2021, Kiely *et al.* 2021, Febria *et al.* 2021). Previously, studies of peatland recovery monitoring used different method,s such as macrofossil analysis techniques (Mauquoy *et al.* 2020), microbial and amoeba-based monitoring (Krashevska *et al.* 2020, Ritson *et al.* 2021), soil physical properties (Salim *et al.* 2021, Word *et al.* 2022, Wahyono *et al.* 2023), soil chemical properties (Arisanty *et al.* 2020, Marcotte *et al.* 2022, Pérez-castillo *et al.* 2023); climate mitigation (Günther *et al.* 2020, Merten *et al.* 2021, Helbig *et al.* 2020); crop recovery (Shepherd *et al.* 2021, Blier-Langdeau *et al.* 2022), peatland-specific species formation (Syaufina and Hamzah 2021, Shepherd *et al.* 2023) and management policies (Miettinen *et al.* 2016, Carmenta *et al.* 2017, Sakuntaladewi *et al.* 2022). On the basis of the results of previous studies on the comparison of carbon content on burned sites with unburned sites, among others, the unburned carbon content is greater than the burned site (Wiggins *et al.* 2018, Wasis *et al.* 2019, Qirom *et al.* 2021); the impact of fire is a decrease in C (Dhandapani and Eversa 2018, Volkova *et al.* 2021, Sulaeman *et al.* 2021). Soil organic matter content varies widely, from low to high/very high. The factors that influence the amount of soil organic matter content include climate, land use type, landform and human activities. C-organic content describes the soil quality conditions both directly and indirectly. The impact of peatland fires resulted in a decrease in C-organic content in Lake Gavur, Turkey (Dikici and Yilmaz 2006); in Kalimantan and Sumatra, Indonesia (Hikmatullah and Sukarman 2015); in Serawak, Malaysia (Ismawi *et al.* 2012). When fires occur, peatlands will experience the process of releasing P (Wang *et al.* 2015, Wasis *et al.* 2019, van Beest *et al.* 2019), so that in the post-fire period there is a decrease in P content (Snyder and Rejmánková 2015). In contrast, the research (Syaufina *et al.* 2022) showed that the post-fire P content increased. Post-fire, the N content will be lower due to evaporation and will increase during recovery (Dhandapani and Eversa 2018, van Beest *et al.* 2019, Sulaeman *et al.* 2021). Post-fire soil potassium content conditions will experience an increase (Syaufina *et al.* 2022). In the areas that experienced fires, there was an increase in the C/N ratio (van Beest *et al.* 2019, Sazawa *et al.* 2018). Peatland improvement is characterized by a decrease in the C/N ratio (Lupascu *et al.* 2020, Anshari *et al.* 2010). In the post-fire recovery period, (van Beest *et al.* 2019) showed that the C, N and P concentrations will increase. Those previous studies showed that the time of natural peatland *recovery* after fire in particular chemical properties are still very limited. This research provided information on the *recovery* rate of post-fire peatlands in the Balangan River – Batangalai River KHG, South Kalimantan. Since the study on the natural recovery time of tropical peatlands, particularly Indonesian peatland after fires is still very limited, this study provided information on the recovery rate of soil chemical characteristics in the post-fire peatlands in the Balangan River-Batangalai River, South Kalimantan. This study aimed to measure peatland recovery of those soil chemical characteristics based on two different time of sampling after the fires in 2015 (taken in 2020 and 2022). Soil chemical properties and characteristics is one of the key-factor of the peatland recovery after burning and it is required in the natural or artificial rehabilitation process. Through the results of its natural recovery, this study can assist the land and forest rehabilitation and/or recovery expertise to speed up the recovery process.

MATERIALS AND METHODS

This study was conducted in the Balangan River - Batangalai River peat hydrological unit, South Kalimantan, Indonesia, which covers a geographical range of 2.34°–2.56° S and 115.22°–115.41° E (Figure 1). The peat soil samples tested came from fire peatlands in 2015 and those that did not experience fires. This study aimed to measure peatland recovery of those soil chemical characteristics based on two different

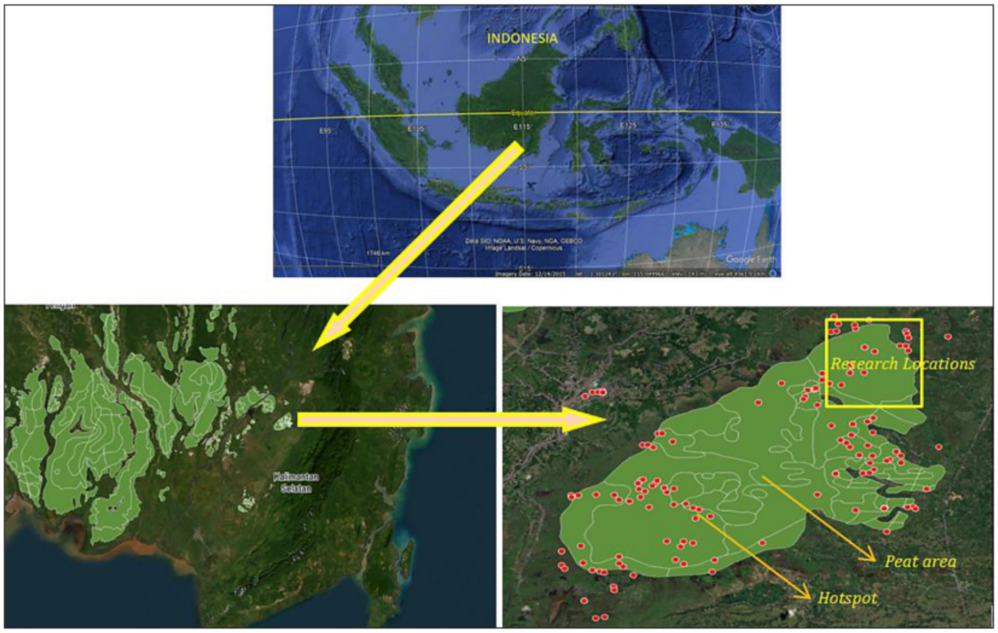

Figure 1. Soil sampling location

time of sampling that are 5 years (Yr+5) and 7 years (Yr+7) after the fires in 2015. The level of peatland recovery is based on soil chemical characteristics, including carbon (C), nitrogen (N), phosphorus (P) and potassium (K) contents. Soil samples were collected at nine different locations that included six locations in the areas that experienced fires in 2015 (P-1, P-2, P-3, P-4, P-5 and P-6) and three locations in the areas that did not experience fires (P-7, P-8 and P-9). Those soil samples were taken in 2020 and 2022 with excavated pits at each sample location at each depth of 10, 20, 30, 40 and 50 cm. A total of 45 samples were tested for carbon, nitrogen, phosphorus and potassium contents.

Figure 2 shows the process of sample collection, preparation and testing. In the sample collection and preparation process, the soil samples were then air-dried and sieved to 2 mm after the fine plant roots were carefully removed. Total carbon content was measured using a spectrophotometer using the following formula (Agus *et al.* 2011, Farmer *et al.* 2014, Qirom *et al.* 2021).

$$\% C = \left(\frac{ppm\ curve \times (ml\ extract/1000)}{weight\ of\ soil\ sample(mg)}\right) \times f_k \times 100 \quad (1)$$

where: *ppm curve* – sample content obtained from the relationship curve between content standard series with its reading after correction of the blank, f_k – moisture content correction factor = 100/(100 – % moisture content).

Total nitrogen content determined using colorimeter with the calculation of the percentage of N-total content in the soil is as follows (Usman 2012, Ramadhan *et al.* 2017):

$$\% N = \frac{(V_c - V_b) \times N \times \frac{50}{25} \times 14}{weight\ of\ soil\ sample(mg)} \times KBK \times 100\% \quad (2)$$

where: V_c – volume of H_2SO_4 sample titration result, N – normality H_2SO_4 (0.05 N), V_b – volume of H_2SO_4 titration result of blank, KBK – dry matter correction.

Phosphorus content using colorimeter and using the formula is as follows (Sulaeman *et al.* 2005):

$$\% P = ppm\ curve\ \times 10 \times \frac{142}{90} \times f_k \quad (3)$$

where: *ppm curve* – sample content obtained from the relationship curve between the level of the standard series with its reading after corrected blanks, *142/90* – conversion factor of the form PO_4 to P_2O_5.

Total potassium content using a flame photometer with the calculation of the percentage of potassium content using the formula (Sulaeman *et al.* 2005):

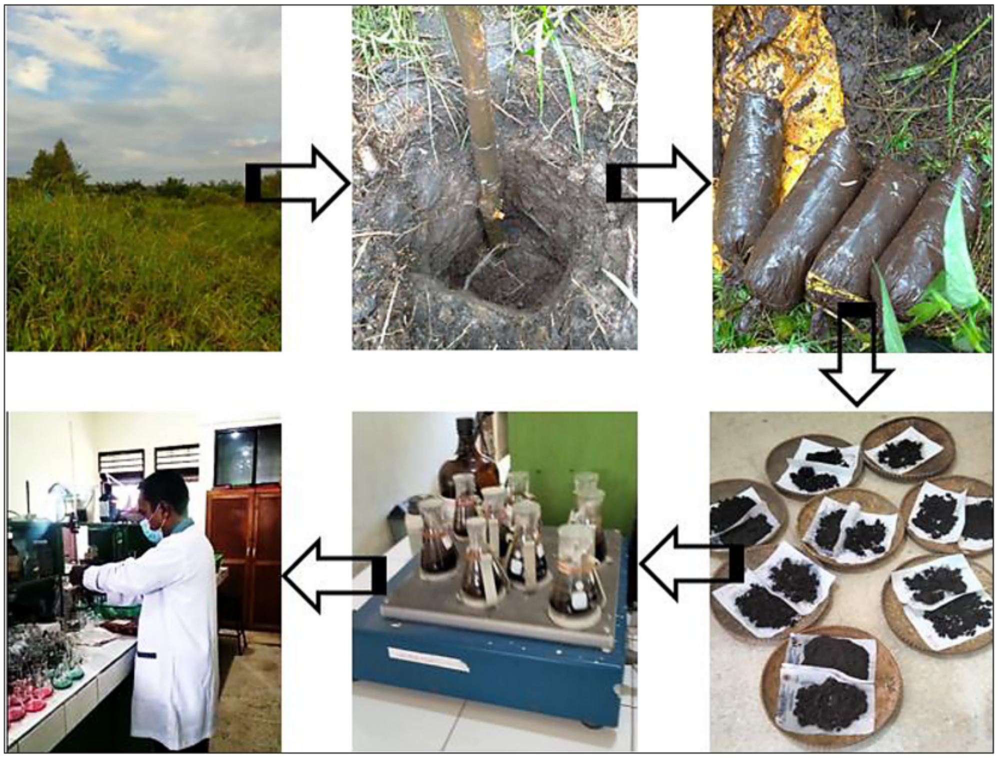

Figure 2. Process sample collection, preparation and testing

$$\% K = ppm\ curve\ \times 10 \times \frac{94}{78} \times f_k \quad (4)$$

where: *94/97* – conversion factor of K form to K_2O.

RESULTS AND DISCUSSION

Chemical characteristics measurement of post-fire peatlands in 2015. Carbon content tests are shown in Figure 3a-c in post-fire and natural/non-fire areas. Figure 4a-c illustrate the nitrogen content of the soil in post-fire and non-fire areas. Figure 5a-c show the results of testing the phosphorus content of the soil in post-fire and non-fire areas. In turn, Figure 6a-c illustrate the results of testing the potassium content of the soil in post-fire and non-fire areas.

Figure 3a shows that the carbon content values in the areas that experienced fires in the five-year post-fire period (2015–2020) are lower than the carbon content values in the areas that did not experience fires. The average value of carbon content at several locations and sample depths in post-fire areas was 15.83% and in the areas that did not experience fires was 22.27%. Figure 3(b) shows that the carbon content value in the burned area within seven years after the fire (2015–2022) is lower than the carbon content value in the non-fired area. The average value of carbon content at several locations and sample depths in post-fire areas was 19.32% and in the areas that did not experience fires was 24.48%. Compared to previous studies (Dikici and Yilmaz 2006, Ismawi et al. 2012), it has the same result which is the value of carbon content in post-fire areas is smaller than in the areas that did not experience fires. Figure 3(c) illustrates the increase in carbon content value from the fifth year to the seventh year after the fire, for the post-fire area there was an increase of 22.00% and in the area that did not experience the fire by 9.90%.

Figure 4a shows that the nitrogen content of the soil in the fifth year after the fire was lower than that in the area without fire. The average value of nitrogen content at several locations

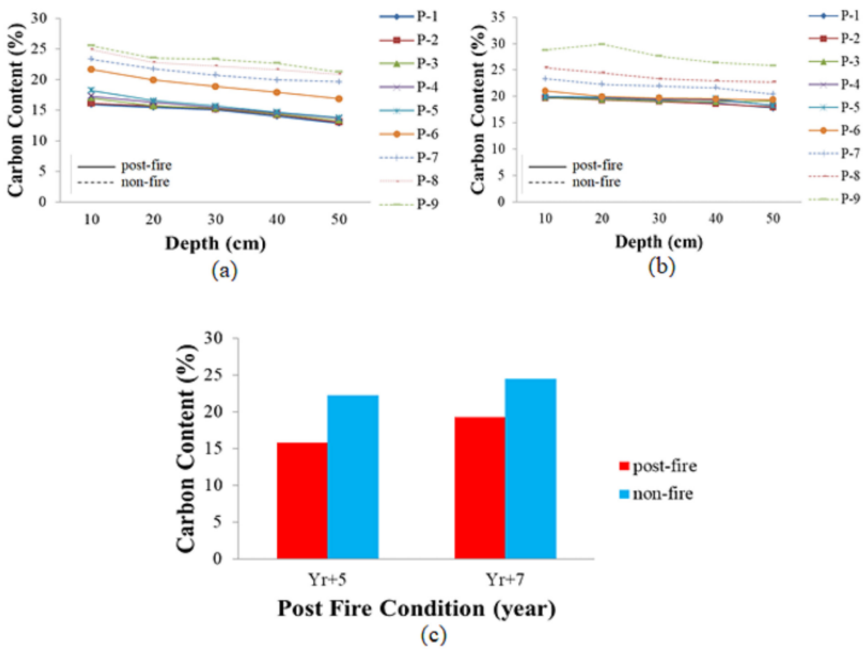

Figure 3. (a) The carbon content of each location at Yr+5, (b) the carbon content of each location at Yr+7, (c) changes in carbon content values at Yr+5 and Yr+9

and sample depths in post-fire areas within five years was 0.69% and in the areas that did not experience fires was 0.80%. Figure 4b shows that the nitrogen content of the soil in the seventh year after the fire was lower than the nitrogen content in the area without fire. The average value of nitrogen content at several locations and sample depths in post-fire areas within seven years was 0.70% and in the areas that did not experience fires was 0.81%. This result has the same tendency with previous studies (Ismawi et al. 2012) that is the value of nitrogen content in post-fire areas is smaller than in the areas that did not experience fires. Figure 4c illustrates the increase in nitrogen content from the fifth year to the seventh year after the fire, for the post-fire area there was an increase of 1.94% and in the area that did not experience the fire by 1.17%.

Figure 5a shows that the phosphorus content of the soil in the fifth year after the fire was lower than the phosphorus content in the area without fire. The average value of phosphorus content at several locations and sample depths in post-fire areas within five years was 0.0075% and in the areas that did not experience fires was 0.0092%. Figure 5b shows that the phosphorus content of the soil in the seventh year after the fire was lower than the phosphorus content in the area without fire. The average value of phosphorus content at several locations and sample depths in post-fire areas within seven years was 0.0078% and in the areas that did not experience fires was 0.0097%. This result has the same trend with previous studies (Ismawi et al. 2012) in which the value of phosphorus content in post-fire areas is smaller than in the areas that did not experience fires. Figure 5c illustrates the increase in phosphorus content from the fifth year to the seventh year after the fire, for the post-fire area there was an increase of 3.19% and in the area that did not experience the fire by 5.11%.

Figure 6a shows that the potassium content of the soil in the fifth year after the fire was lower than the potassium content in the area without fire. The average value of potassium content at several locations and sample depths in post-fire areas within five years was 10.39% and in the areas that did not experience fires was 14.16%. Figure 6(b) shows that the phosphorus content of the soil in the seventh year after the fire was lower than the potassium content in the area without fire. The average value of potassium content at

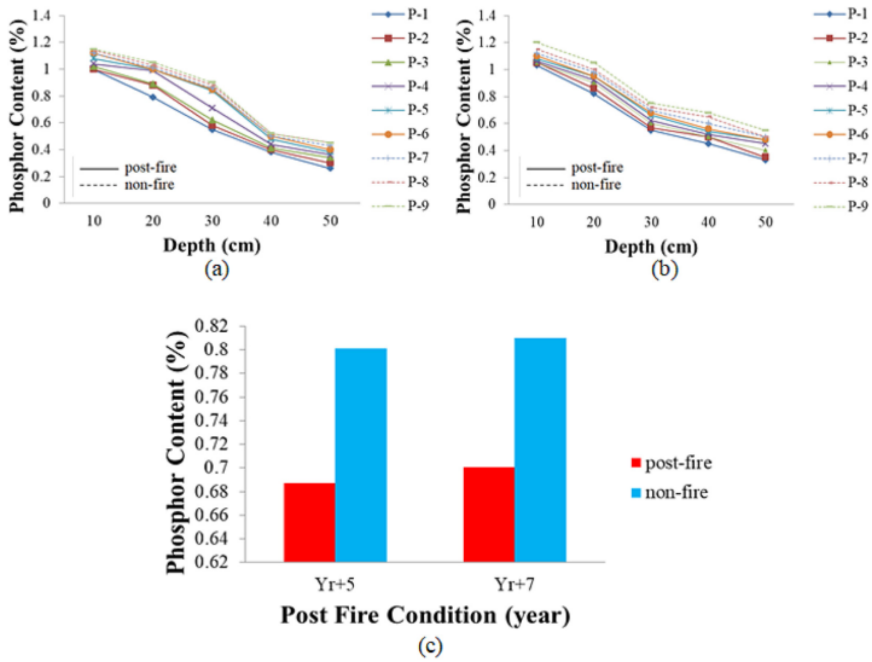

Figure 4. (a) The nitrogen content of each location at Yr+5, (b) the nitrogen content of each location at Yr+7, (c) changes in nitrogen content values at Yr+5 and Yr+9

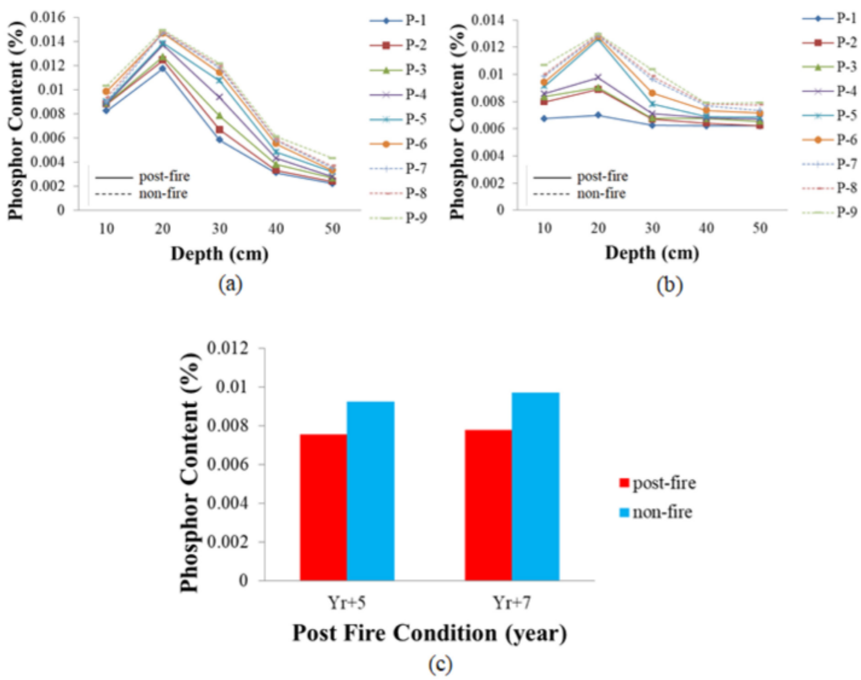

Figure 5. (a) The phosphorus content of each location at Yr+5, (b) the phosphorus content of each location at Yr+7, (c) changes in phosphorus content values at Yr+5 and Yr+9

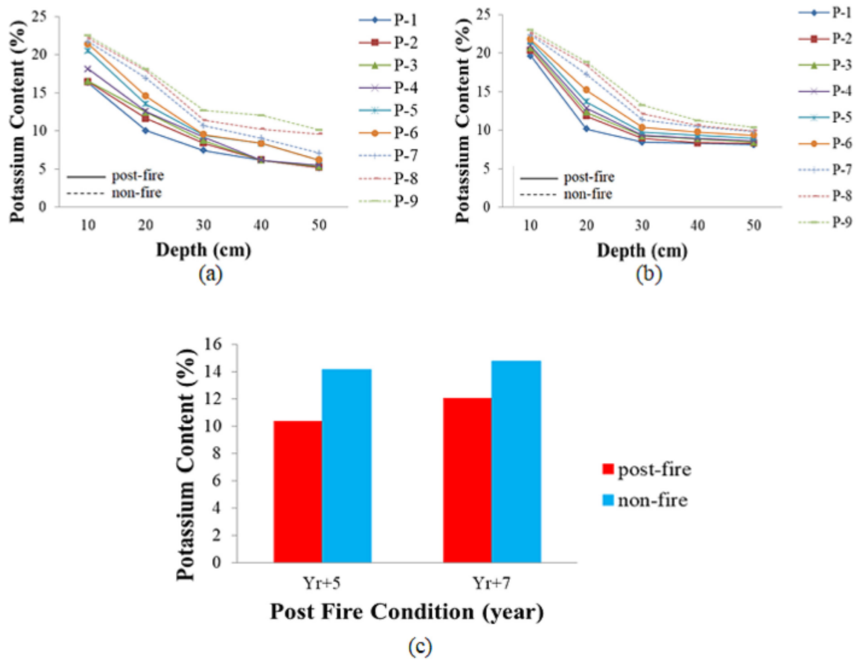

Figure 6. (a) The potassium content of each location at Yr+5, (b) the potassium content of each location at Yr+7, (c) changes in potassium content values at Yr+5 and Yr+9

several locations and sample depths in post-fire areas within seven years was 12.09% and in the areas that did not experience fires was 14.78%. This result is similar with previous studies (Ismawi et al. 2012) that is the value of potassium content in post-fire areas is smaller than in the areas that did not experience fires. Figure 6c illustrates the increase in potassium content from the fifth year to the seventh year after the fire, for post-fire areas there was an increase of 16.33% and in the areas that did not experience the fire by 4.44%.

Figure 7a illustrates the increase in the ratio of carbon content to nitrogen from the fifth year to the seventh year after the fire, for post-fire areas there was an increase of 9.68% and in the areas that did not experience the fire by 8.63%. Figure 7b illustrates the increase in the comparison of carbon content values with phosphorus from the fifth year to the seventh year after the fire, for post-fire areas there was an increase of 18.24% and in the areas that did not experience the fire by 4.56%.

The C/N value is one measure of the condition of peatland degradation (Ismawi *et al.* 2012, Krüger *et al.* 2015, Leifeld *et al.* 2020). C/N values are > 30 under natural conditions and < 30 under degraded conditions (Liimatainen *et al.* 2018, Liu *et al.* 2019); degraded < 25 (MacDonald *et al.* 2002); degraded < 20 (Anshari *et al.* 2010) and < 15 (Leifeld *et al.* 2020). In this research, the C/N test results on burned land Yr+5 amounted to 23.05 and Yr+7 amounted to 27.58 and on natural land Yr+5 amounted to 27.82 and Yr+7 amounted to 30.22. According to the test results, the C/N value has increased. According to (Anshari *et al.* 2010, Leifeld *et al*. 2020) post-fire land conditions have experienced land improvement.

The increase in C/P value is one of the benchmarks for the improvement of peatland conditions from land degradation (Ismawi *et al.* 2012). The increase in C/P value on the burned land Yr+5 was 2098.62 and Yr+7 was 2481.32 and on the natural land Yr+5 was 2411.93 and Yr+7 was 2521.84. According to the test results, there was an increase in the C/P value, which illustrates that the condition of the peatland has an improvement.

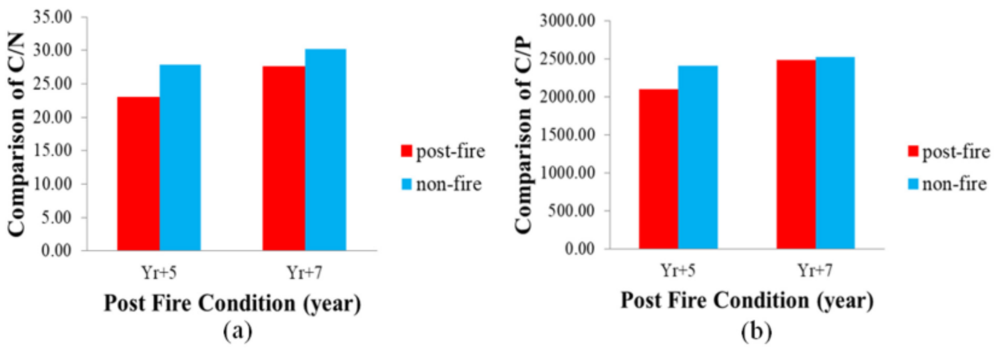

Figure 7. (a) Comparison of carbon content with nitrogen at Yr+5 and Yr+9, (b) comparison of carbon content with phosphor at Yr+5 and Yr+9

Table 1. Test results and sample calculations

No.	Condition	Carbon (%)		Nitrogen (%)		Phosphor (%)		Potassium (%)		C/N		C/P	
		T+5	T+7	T+5	T+7	T+5	T+7	T+5	T+7	T+5	T+7	T+5	T+7
1	Burn	15.83	19.32	0.69	0.70	0.0075	0.0078	10.39	12.09	23.05	27.58	2098.62	2481.32
2	Unburn	22.27	24.48	0.81	0.81	0.0092	0.0097	14.16	14.78	27.82	30.22	2411.93	2521.84
Percentage change from T+5 to T+7													
1	Burn	22.00		1.94		3.18		16.33		19.68		18.24	
2	Unburn	9.90		1.17		5.11		4.44		8.63		4.56	

CONCLUSIONS

This study showed chemical properties recovery rate of post-fire peatlands in the Balangan River-Batangalai River, South Kalimantan. The peat soil samples tested came from peatlands after the 2015 fires and those that had not experienced fires in the timeline of five years (Yr+5) and seven years (T+7) afterwards. This study found that the direction of all measured chemical properties of the investigated post-fire peat soil are increasing. In general, the increase in carbon, nitrogen, phosphorus, potassium, C/N ratio and C/P ratio in post-fire peatlands indicates an enhanced condition. This study can provide supporting information for the regulator, management or expertise of the land and forest rehabilitation to speed up the recovery process.

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