Effects of peat fires on soil chemical and physical properties: a case study in South Sumatra

D Sulaeman\textsuperscript{1}, E N N Sari\textsuperscript{1} and T P Westhoff\textsuperscript{2}

\textsuperscript{1} World Resources Institute Indonesia, Jakarta, Indonesia
\textsuperscript{2} Independent Researcher, Wageningen, The Netherlands

E-mail: dede.sulaeman@wri.org

Abstract. Peat fires have been an annual environmental crisis in Indonesia. In 2015, large parts of the country's peat were burned, impacting the health, education, and livelihoods of millions of Indonesians. Communities living on peat have practiced the burning of peatlands for a long time as they are convinced that this process will improve soil fertility. However, this assumption is not justified. This study examined the effect of a peat fire in 2019 in South Sumatra by comparing samples taken on an affected and unaffected smallholder oil palm plantation. These samples were analyzed to see the impact of fires on the peat soil. Results show that the ash content increased drastically by 57%. The fires improved the soil pH by 6%. However, the severe peat fires also caused negative impacts on soil fertility by reducing total nitrogen (6%), cation exchange capacity (8%) and soil organic carbon (2%). Furthermore, this study showed that peat fires decrease water retention capacity by 1 to 12%. Contrary to popular belief among local farmers, this study shows the negative consequences of slash and burn activities on peat chemical and physical properties.

1. Introduction

Peatlands have been widely known as an important landscape on earth for a multitude of reasons, including its critical role in climate change. While peatlands cover only a very small percentage of the global landmass, they store a tremendous amount of carbon, equivalent to one-third of the total global soil carbon [1]. As such, peatland preservation is crucial to keeping the carbon stored in the soil and preventing CO\textsubscript{2} emission. Tropical peatlands cover 0.25% of the global surface but contain 3% of the global soil carbon stocks, making them significant carbon sinks [2]. Indonesia is amongst the countries with the largest tropical peat swamp in the world, with approximately 14.9 million ha of tropical peat soil, or more than 30% of the global tropical peat area [3]. Around 34% of Indonesia’s peat is located in Sumatra [4].

Despite this important role, developments in the natural peat swamp forests over the past decades have not reduced the chances of fire recurrence. Land clearance activities continued, and forest cover on peatlands decreased from 77% to 36% within the period of 1990 to 2010 [5]. Human activities on peatlands typically involve peat drainage through man-made canals. This is usually done not only to make the land more suitable for agriculture but also transportation purposes. The problem is that dry peat is highly flammable. This means that fire can easily take hold in areas of drained peatland, and fires are incredibly difficult to extinguish as they burn underground. This was the case in the Mega Rice Project in Kalimantan, which began in 1996 and had converted about 1 million ha of peat swamp forest...
into paddy fields [6]. This project was unsuccessful and later discontinued, but the constructed drainage canals have changed the hydrological condition of the area and increased the risk of peat fires [7].

The importance of the Indonesian peatlands as carbon stock has become more and more recognized since the widespread fires of 1997. The total emission of this event was estimated to be between 0.81 and 2.57 Gt of carbon, equivalent to 13 to 40% of the mean annual emission from fossil fuels [8]. These fires were caused by the drainage of the peat areas and land clearance activities in combination with an unusually long El Niño event, which created a dry period in Indonesia. In 2015, the country suffered one of its worst burning seasons in years. Large parts of the country’s land and forest area (around 2.6 million ha) have been burning out of control since June 2015, impacting the health, education, and livelihoods of millions of Indonesians living in the areas with the worst burning. This has also resulted in 16.1 billion dollars worth of damages and losses [9].

Land and forest fires still occurred in Indonesia during 2016-2019 and 2019 fires had been the worst since 2015. According to the Directorate General of Climate Change, Ministry of Environment and Forestry of Indonesia, the fires affected more than 1.6 million ha of land and forest during 2019 [10]. Land and forest fires are a major cause of land surface changes, affecting the climate system, vegetation composition and chemical composition of the atmosphere. These events constitute the largest source of primary fine carbonaceous particles and the second-largest source of trace gases in the global atmosphere [11].

Land clearance activities are among the driving factors behind fires in Indonesia. Communities living on peat have practiced the burning of peatlands for a long time as they are convinced that this process will improve the peat soil fertility. Peat fires increase the soil pH (decreased soil acidity) [12,13], a condition more favourable for agricultural activities and increased nutrient availability [14]. However, little is known about the negative effects of these fires on other peat chemical and physical characteristics. This research aims to fill this knowledge gap by investigating the difference in soil parameters between a burned and unburned plantation.

2. Materials and methods

The research was conducted in an oil palm plantation in Rantau Keroya Village, Musi Banyuasin Regency, South Sumatra Province (Figure 1). Peat fires occurred in the area throughout October 2019. This research was carried out in three stages: 1) a desktop study to select the research site, both for the burned and unburned areas, 2) soil sampling aimed at collecting disturbed and undisturbed soil samples in the field, and 3) laboratory analysis to analyse soil chemical and physical properties in the laboratory.

PRIMS (Peatland Restoration Information and Monitoring System) data was used in the selection of research sites. PRIMS is a spatial-data-based online platform owned by the Indonesian Peat Restoration Agency (Badan Restorasi Gambut/BRG) that provides up-to-date information on the condition of peatlands in Indonesia and the progress of peatland restoration efforts in seven priority provinces, including South Sumatra. PRIMS provides degradation indicators, especially hot-spot data, that can be used to indicate the land and forest fires event. The data was overlaid with the peat hydrological unit (PHU) and administrative data to select the burned area.

Since peat soils are highly heterogeneous, adequate soil sampling must be done to collect the most representative samples that will be able to characterize the properties of a field as accurately and inexpensively as possible. Three sampling points each were selected for the burned and unburned area using the randomized soil sampling method. Soil samples were collected using the Eijkelkamp peat auger for disturbed soil samples and ring sampler for undisturbed soil samples from 0 to 30 cm of peat depth in November 2019. Undisturbed soil samples are samples that structure is similar to the peat's actual structure in the field. Disturbed soil samples are those whose structure is different from the original structure due to disturbances during sampling, handling, and transportation [15]. Undisturbed and disturbed soil samples were taken to measure soil physical and chemical properties, respectively. The soil chemical properties that analysed in this study were soil pH, total nitrogen, available phosphorus, and cation exchange capacity. Total carbon, fiber, and ash content were also analyzed using
disturbed soil samples. The physical properties investigated in this study include soil water retention capacity at pF 1, 2, 2.54 and 4.2.

![Figure 1](image.png)

**Figure 1.** The Sampling area in Musi-Penukal Peat Hydrological Unit, South Sumatra.

Disturbed soil samples taken from the field were analysed in the laboratory of Soil Science and Land Resources Department, Faculty of Agriculture, IPB University. Meanwhile, undisturbed soil samples were analysed in the laboratory of ICBB (Indonesian Center for Biodiversity and Biotechnology), Bogor.

Soil pH refers to the acidity or alkalinity of the peat soil. It is a measure of the concentration of free hydrogen ions (H\(^+\)) in the peat soil. This parameter was determined using a pH meter with a glass electrode at a water suspension ratio of 1:5. Nitrogen (N) and Phosphorus (P) are among the primary macronutrients, which are essential for plant growth. The Kjeldahl method was used to determine the total nitrogen content, and available phosphorus (P\(_2\)O\(_5\) content) was measured using Bray I method. The Cation Exchange Capacity (CEC) is a measure of the ability of a soil to hold cations. It is a fundamental soil property influencing soil nutrient availability, soil pH, and the soil’s reaction to fertilizers and other ameliorants [16]. This soil parameter was determined by using the NH\(_4\)OAc-method.

Peatlands are ecosystems with a particular characteristic of high organic matter content. The organic carbon and ash content of the peat soil were determined based on the dry combustion (loss on ignition/LOI) method at 550 to 600°C. Fiber content was analyzed by filtering at 100 meshes (0.149 mm). Total CO\(_2\) emission (below ground) from peat fires were estimated using the following calculation [15]:

\[
E_{bb} = \text{Volume of burned peat (m}^3\text{) x BD (t/m}^3\text{) x C org (t/t) x 3.67 CO}_2/C
\]

Where:

- \(E_{bb}\) : \(\text{CO}_2\) emissions due to peat fire. When a layer of peat is completely burned, organic matter will be oxidized, resulting in the release of \(\text{CO}_2\), \(\text{H}_2\text{O}\) and some of other gases.
- \(BD\) : peat bulk density
- \(C\ org\) : peat organic carbon
The bulk density is recognized as one of the defining physical parameters of peat, and its characterization is essential to any estimation of peatland carbon stocks and CO$_2$ emission. Bulk density (BD) was determined using the gravimetric method.

The pressure plate (pF) method was used to measure peat water holding capacity. This parameter was measured quantitatively using the pressure plate and pressure membrane apparatus (moisture retention or pF analysis). Fully saturated soil samples were put in contact with a saturated porous plate, and the whole plate was submitted to a given pressure [17] at 0.01, 0.1, 0.33 and 15 bar [18] for pF 1, pF 2, pF 2.54 and pF 4.2, respectively.

Data analysis was carried out by comparing samples taken on the burned and unburned area. Data was analyzed using an independent sample t-test. Environmental damage analysis was carried out using the criteria from the Indonesian Government Regulation No. 4/2001 on Environmental Damage and Pollution Control Associated with Forest and Land Fires.

3. Results and discussion

It is widely known that peat fires can affect the environment in many ways. Besides its impact on worsening climate change, peat fires also affect the physical, chemical, and biological properties of peat soil. This study shows that peat fires in the study area combusted 0.1 m of the peat layer, causing environmental damages by decreasing the soil’s organic carbon (figure 2), total nitrogen (figure 5), cation exchange capacity (figure 7), and water retention (figure 8-9). Peat fires also affected soil pH (figure 4) and available phosphorus (figure 6). Both parameters were increased due to fires. Increased soil pH and available phosphorus are also classified as environmental damages according to the Indonesian Government Regulation No. 4/2001 because these conditions change the nutrient balance in the burned area.

3.1 Soil organic carbon and CO$_2$ emissions

Soil carbon is an essential element for soil quality, holding soil nutrients for plant uptake, soil conservation, and the overall natural soil systems that are the fundamental requirements for the soil security and food production. Moreover, peat soils are the vital storehouses of organic carbon, which can potentially be harnessed for climate change mitigation purposes [19]. Tropical peat has an average carbon content of 56.0% [20] and the carbon content of Southeast Asian peat is in the range of 41.6 to 62% [21]. This study shows that peat fires significantly affect soil organic carbon content (p<0.05), reduced the parameter by 2%. Soil organic carbon in the unburned area is higher than in the burned area, with a value of 56 and 54.9% respectively (figure 2). Another study [13] showed that soil organic carbon decreased due to fires with a value of 55.3% for unburned peat and 53.2% for burned peat.

![Figure 2. Carbon organic content comparison between burned and unburned peat.](image-url)
Peat is an accumulation of decayed vegetation formed in anaerobic conditions. As an organic porous media, the carbon-rich soil is prone to small ignition and combustion once the level of moisture contents drops to a certain level [22]. The burned peat in the study area was 0.1 m of peat depth with the value of bulk density of 0.34 t m$^{-3}$ on average. Based on the calculation of CO$_2$ emissions due to fires [15], it is estimated that 684 t CO$_2$ ha$^{-1}$ has been emitted to the atmosphere during the fires. The carbon emission for the first fires in the Mega Rice Project (MRP) area in Central Kalimantan reached 114 t C ha$^{-1}$ or 418 t CO$_2$ ha$^{-1}$ [23]. Oil palm cultivation on peatlands needs to involve soil compaction to increase bearing capacity of the soil. It caused the increase of soil bulk density and caused the higher carbon emission in the research area than the MRP project.

3.2 Ash & fiber content

The level of ash in peat soil shows the amount of mineral content in the peat. Peats, with a large content of mineral soil, have a high ash value. In good quality peats, ash values can range from 1 to 7%. The average value of ash content on each peat in the study area was 2.24%. As hypothesized, fire events will increase the ash content of the peat by 57%. Our results showed that the unburned area is higher than the average with 3.4%, but the fires have significantly altered the ash content to 5.3% (figure 3).

![Figure 3. Fiber and ash content comparison between burned and unburned peat.](image)

Peatlands, with a large number of minerals, have a high ash content, which negatively affects the peat’s ability to burn. Ash contents vary widely throughout Indonesia, from 0.7% in Banjarmasin to 40.9% in Pontianak [24]. On average, the Indonesian peatlands have an ash content of 1.1%, where it can exceed 5% if deposits are closely located [25].

As expected, the fiber content will decrease due to the fires from 46.7% to 40.0% (figure 3). These numbers comply with earlier research, which saw a range of 38 to 75% of fiber content [26]. However, the result is not statistically significant (p>0.05).

3.3 Soil pH

The tropical peatlands of this case study are ombrogenous, which means they are formed by rain. A feature of ombrogenous peats is their low pH of 3 to 4.5 [24]. This low pH was observed in burned and unburned peatlands with a pH of 3.2 and 3.0 respectively (figure 4). This result showed that the soil pH slightly increased (soil acidity decreased) by 6% after the fires. However, the change is too subtle to speak of higher agricultural potential, and the difference is also not statistically significant (p>0.05). Another study [12] showed the same result where the occurrence of forest fires can slightly increase the value of soil pH with 4.11 and 4.23 for unburned and burned peat respectively.
Soil acidity usually decreases after fire events due to the destruction of organic acids and the contribution of carbonates, bases and oxides from ash. It is a well-known fact that the cations (K\(^+\), Na\(^+\), Ca\(^{2+}\) and Mg\(^{2+}\)) released from combusting soil organic matter can increase soil pH by displacing H\(^+\) and Al\(^{3+}\) ions adsorbed on the negative charge of the soil colloids [27]. Fires provide input of minerals (ash and charcoal) in the soil to increase soil pH [12]. Soil pH may recover very quickly after the removal of ash by the leaching process. It must be noted, however, that the pH measurement was not done in the field. During transportation from the field to the lab, the peat samples can be oxidized, and this can influence the pH value [24].

3.4 Total nitrogen
Nitrogen (N) is a vital nutrient because it is one of the primary macronutrients that will most likely limit tree growth in forests and other ecosystems. The amount of total N volatilized during combustion has been reported to be directly proportional to the amount of organic matter combusted [28]. Most of this volatilized N (up to 99\%) reverts to N\(_2\) [29].

As expected, the amount of nitrogen slightly decreased by 6\% due to the fires. The unburned peat has 1.6\% of N and the burned 1.5\% of N (figure 5). While a difference is observed, it is small and statistically insignificant (p>0.05). Nevertheless, it should be noted that even small losses can adversely affect the long-term productivity of N-deficient ecosystems [30]. The amount of nitrogen matches earlier research, which ranged between 0.3 and 4.0\% of nitrogen [24]. Another study [13] showed that peat fires in Indragiri Hilir, Riau Province affected total nitrogen content, with 2.30\% for unburned peat which later dropped to 1.97\% after the fires. The loss of biomass during the burning of peat is accompanied by the volatilization of N, leaving remnants of biomass that are resistant in subsequent decomposition [31]. Volatilization is the chemically driven process most responsible for N losses during fire [30].

![Figure 4. Soil pH comparison between burned and unburned peat.](image)

![Figure 5. N-total comparison between burned and unburned peat.](image)
Temperature thresholds play a significant role in N volatilization. Because of the low threshold temperatures for N, the nutrient is readily volatilized from organic matter during combustion. Threshold temperatures are defined as temperatures at which the volatilization of a nutrient occurs. These thresholds can be divided into three general nutrient categories: sensitive, moderately sensitive, and relatively insensitive. Nitrogen is considered sensitive because its thresholds can be as low as 200°C. For comparison, Phosphorus and Calcium have a higher threshold temperature at 774 and 1484°C, respectively [30].

3.5 Available phosphorus (P$_2$O$_5$)
Phosphorus is perhaps the second most limiting nutrient found in natural ecosystems. Organic soils in virgin conditions usually have very low phosphorus contents. Most phosphorus is present in the organic form and must be mineralized first before it is available to the plant [24]. The amount of phosphorus was observed to be higher in the burned area, at 174 mg kg$^{-1}$ compared to 29 mg kg$^{-1}$ in the unburned area (figure 6) and the difference is statistically significant (p<0.05). Another study [31] showed that available phosphorus in the burned area had a higher value compared to the unburned area, with a value of 47 mg kg$^{-1}$ for the burned area. A change in pH can change the amount of available phosphorus in the peat soil, which was most likely the case here.

Andriesse [24] stated that burning is beneficial in increasing the pH value and changes unavailable phosphorus, stored in the organic compounds of the peat, into available forms. It is well documented in the literature that fire causes the release of P from organic matter, especially following partial combustion of organic matter, where bioavailable P is increased, which is accompanied by an increase in pH [14]. However, based on other studies [24,31], the improvement of soil pH and available phosphorus is short-lived and requires the re-burning of the peat to improve the values, making this practice unsustainable.

![Figure 6. Available Phosphorus (P$_2$O$_5$) comparison between burned and unburned peat.](image)

3.6 Cation exchange capacity (CEC)
Cation exchange is the interchange between cations in solution and different cations adsorbed on the surface of any negatively charged materials such as clay or organic colloids (humus). Cation exchange capacity is the sum of the exchangeable cations found on organic and inorganic soil colloids. Cation exchange capacity sites are important storage places for soluble cations found in the soil. The adsorption of cations prevents the loss of these cations from the soils by leaching following a fire event [30].

The average value of Cation Exchange Capacity in Indonesia is around 125 cmol$_{(c)}$ kg$^{-1}$ [30]. Hikmatullah and Sukarman’s study [32] showed that the CEC of peat soils in Kalimantan and Sumatra were high to very high, in the range of 28 to 127 cmol$_{(c)}$ kg$^{-1}$. The soil parameter is strongly influenced by organic carbon content. Fire directly affects the cation exchange capacity by combustion of soil organic matter. This study shows that peat fires reduced CEC by 8%, where the burned area has a lower CEC with 136 cmol$_{(c)}$ kg$^{-1}$, compared to the unburned area with 148 cmol$_{(c)}$ kg$^{-1}$ (figure 7). However,
the difference is statistically insignificant (p>0.05). This result is in line with a previous study. The CEC of peat decreased from 121.9 cmol(+)/kg to 111.2 cmol(+)/kg after fires [31].

**Figure 7.** Cation exchange capacity comparison between burned and unburned peat.

3.7 Water retention capacity

Peatlands have a large water retention capacity [33], which correlates with the fact that this ecosystem contains a huge number of organic materials. It plays a huge role as a "sponge" by storing large water volumes in the rainy season and releasing this water gradually during the dry season. This study shows that water retention capacity at pF 1 and pF 2 decreased by 5% for both values due to fires (figure 8). Intense fire can result in the development of hydrophobic compounds in surface peat [34]. The compounds cause a decrease in water retention capacity due to the change of its characteristics and structure after fires [35].

**Figure 8.** Water retention at pF 1 and pF 2.

Peat water retention capacity in this study was also measured at field capacity and permanent wilting point. Field capacity is the amount of water held at the suction of 0.33 bar or at a pF of 2.54 (the pF being the logarithm of the height of water in centimeters). Permanent wilting point is the moisture content at 15 bar section or pF 4.2 [19]. This study shows that burning the peatlands caused a slight decrease in water retention capacity at pF 2.54 and pF 4.2 with 1 and 12%, respectively. However, the difference is not statistically different (p>0.05) for peat water retention capacity at all given pressure level.
4. Conclusions
Peat fires affect peat soil characteristics, both the chemical and physical properties of the soil. Ash content increases after fires and leads to the improvement of Soil pH (decreasing soil acidity). Fire events also increased available phosphorus. However, a previous study suggests that this increase is short-lived, and it requires re-burning the peat to maintain this improvement, making this practice far from sustainable. Furthermore, peat burning causes adverse impacts in the form of decreased cation exchange capacity, total nitrogen, and water retention capacity. Soil organic carbon also decreased following fire events, emitting a huge amount of carbon to the atmosphere that worsens climate change. When sustainable land management is the aim, peat burning practice should be avoided.

Acknowledgments
This research was part of PRIMS (Peatland Restoration Information and Monitoring System) project activities supported by the Government of Norway through the United Nations Office for Project Services (UNOPS).

References
[1] Murdiyarso D and Kauffman J 2011 Addressing climate change adaptation and mitigation in tropical wetland ecosystems of Indonesia InfoBrief. 41
[2] Page S E and Banks C 2007 Tropical peatlands: distribution, extent and carbon storage—uncertainties and knowledge gaps Peatlands International 2 26–7
[3] Agus F, Anda M, Jamil A and Masganti 2014 Lahan gambut indonesia: pembentukan, karakteristik, dan potensi mendukung ketahanan pangan (in Bahasa) (Jakarta: IAARD Press) p 246
[4] Warren M, Hergoualc’h K, Kaufman J B, Murdiyarso D and Kolka R 2017 An appraisal of Indonesia's immense peat carbon stock using national peatland maps: uncertainties and potential losses from conversion J. Car. Bal. Man. 12
[5] Jukka M, Chenghua S and Soo Chin L 2012 Two decades of destruction in Southeast Asia’s peat swamp forests Front. in Ecol. Envi. 10 124-8
[6] Boehm H D V and Siegert F 2001 Proc. Int. Symp. on Trop. Peat. (Jakarta: BPPT and Indonesian Peat Association)
[7] Rieley J O, Notohadiprawiro T, Setiadi B and Limin S H 2008 Restoration of tropical peatland in Indonesia; why, where and how? Trop Peat 2 40-44
[8] Page S E, Siegert F, Rieley J O, Boehm H D V, Jaya A and Limin S 2002 The amount of carbon released from peat and forest fires in Indonesia during 1997 Nature 420 (6) 1-5
[9] World Bank 2016 The Cost of Fire: An Economic Analysis of Indonesia’s 2015 Fire Crisis (Jakarta: World Bank) p 9

Figure 9. Water retention at pF 2.54 and pF 4.2.
[10] Sipongi 2020 Rekapitulasi luas kebakaran hutan dan lahan (ha) per provinsi di Indonesia tahun 2015-2020 (in Bahasa) (Jakarta : Ministry of Environment and Forestry) p 2
[11] A Pribadi and G Kurata 2017 IOP Conf. Ser.: Earth Environ. Sci. 54
[12] Ibrahim, Harlen, Sukendi and Siregar Y I 2019 Conf. Ser.: Earth Environ. Sci. 383
[13] Wasis B, Saharjo B H and Putra E I 2019 Impacts of peat fire on soil flora and fauna, soil properties and environmental damage in Riau Province Indonesia J. Biod. 20 (17) 70-75
[14] Beest C V, Petrone R, Nwaishi F, Waddington J M and Macrae M 2019 Increased peatland nutrient availability following the fort McMurray Horse River wildfire Diversity. 11 142
[15] Agus F, Hairiah K and Mulyani A 2011 Measuring carbon stock in peat soils: practical guidelines (Bogor: World Agroforestry Centre Southeast Asia Regional Program, Indonesian Centre for Agricultural Land Resources Research and Development) p 60
[16] Hazleton P and Murphy B 2007 Interpreting soil test results what do all the numbers mean? (Sydney: NSW Department of Natural Resources) p 152
[17] Braudeau E, Hophannissan G, Assi A T and Mohtar R H 2014 Soil water thermodynamic to unify water retention curve by pressure plates and tensiometer Frontiers in Earth Sci. 2 13
[18] Indahyani S, Sumawinata B and Darmawan 2017 Measurement of water retention of peat soil using combination of three phase meter and ceramic plate (in Bahasa) Buletin Tanah dan Lahan 1 (10) 9-14
[19] Uddin J, Mohiuddin A S M and Hassan M. 2019 Organic carbon storage in the tropical peat soils and its impact on climate change J. Clin. Chan. 8 94-109
[20] Hu Y, Anez NF, Smith TEL, and Rein G 2018 Review of emissions from smouldering peat fires and their contribution to regional haze episodes J. Wild. Fire. 27 293–312
[21] Page S E, John O R and Christopher J B 2011 Global and regional importance of the tropical peatland carbon pool Glob. Chan. Bio. 17 798–818
[22] Restuccia F, Huang X, Rein G 2017 Self-ignition of natural fuels: can wildfires of carbon-rich soil startby self-heating? J. Fire. Safe. 91 828-834
[23] Page S E and Hooijer A 2016 In the line of fire: the peatlands of Southeast Asia Phil. Trans. R. Soc. B 371
[24] Andriesse J P 1988 Nature and management of tropical peat soils (Rome: Food And Agriculture Organization of The United Nations) p 187
[25] Neuzil S G, Supardi, Cecil C B, Kane J S and Soedjono K 1993 Inorganic geochemistry of domed peat in Indonesia and its implication for the origin of mineral matter in coal (Boulder: The Geological Society of America) p 286
[26] Ratnaningsih A T and Prasyaningsih S R 2017 IOP Conf. Ser.: Earth Environ. Sci. 97
[27] Sazawa K, Wakimoto T, Fukushima M, Yustiawati, Syawal M S, Hata N, Taguchi S, Tanaka S, Tanaka D and Kuramitz H 2018 Impact of peat fire on the soil and export of dissolved organic carbon in tropical peat soil Central Kalimantan Indonesia J. Earth Space Chem . 2 692-701
[28] Raison R J, Khanna P K and Woods P V 1985 Mechanisms of element transfer to the atmosphere during vegetation fires Canadian J. For. Res. 15 132-40
[29] DeBell D S and Ralston C W 1970 Release of nitrogen by burning light forest fuels J. Soil Sci. Soc. Amer. 34 936-8
[30] Knoepp J D, DeBano L F and Neary D G 2005 Wildland fire in ecosystems: effects of fire on soils and water chapter 3 (Ogden: U.S. Department of Agriculture) pp 53-71
[31] Astiani D, Widiastuti T, Latifah S and Simatupang D 2020 Soil characteristics and CO2 emissions of ex-burnt peatland in Kubu Raya District West Kalimantan Indonesia J. Biod. 21 (36) 91-98
[32] Hikmatullah and Sukarman 2014 Physical and chemical properties of cultivated peat soils in four trial sites of ICCCTF in Kalimantan and Sumatra Indonesia J. Trop. Soils 19 (1) 31-41
[33] Rezanezhad F, Price J S, Quinton W L, Lennartz B, Milojevic T and Cappellen P V 2016 Structure of peat soils and implications for water storage, flow and solute transport: A review update for geochemists J. Chem. Geol. 429 75-84
[34] Brown L E, Holden J, Palmer S M, Johnston K, Ramchunder S J and Grayson R 2015 Effects of fire on the hydrology, biogeochemistry, and ecology of peatland river systems J. Fresh. Scie. 34 140 6–25

[35] Perdana L R, Ratnasari N G, Ramadhan M L, Palamba P, Nasruddin and Nugroho Y S 2015 IOP Conf. Ser.: Earth Environ. Sci. 105