Changes in chemical and physical properties of hemic peat under fire-based shifting cultivation

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ABSTRACT Fire is still the best tool for land preparation for shifting cultivation, because it is quick, cheap and easy. Unfortunately, it is not clear whether or not shifting cultivation is sustainable in terms of quality and duration. To elucidate this, research was conducted on shifting cultivation land in the village of Pelalawan, Pelalawan district, Riau Province, Indonesia. The research was conducted during dry season in the year 2001. The main objective was to determine changes in the soil's chemical and physical properties three and six months after burning.

Results of research show that the fuel load in the site varied from 39.5-51.8 ton ha⁻¹ and consisted of litter and branches, the fuel bed depth varied from 71.8 to 108.4 cm and the rate of fire spread varied from 1.1 to 2.5 m minute⁻¹ and resulted in high flame temperatures that varied from 900 to 1100 °C. The high flame temperatures were accompanied by high fire intensities that varied from 2552.3 to 5050.9 kW m⁻¹ caused peat destruction that ranged from 6.0 to 7.2 cm depth. At three months after burning there was only base saturation in hemic 2 increased significantly, while at six months there was only base saturation in both hemic 2 and 3. As for soil physical properties, it was found that only the water holding capacity increased at three and six months after burning.

Key words: Hemic, fire, peat, chemical properties, physical properties

INTRODUCTION

Shifting cultivators use fire to prepare their land, because it is cheap and easy to do; it has been done for thousands years (Goldammer, 1993) without any environmental problems like those that occur now, such as peat destruction and haze. Shifting agriculture systems in their early practice were done when there was low human population pressure on the forest resources. These systems provided a sustainable base of subsistence for indigenous forest inhabitants, and had little effect on overall forest ecosystem stability (Nye & Greenland, 1960). Ash made by burning is rich in the minerals phosphorus, magnesium, potassium, and sodium. The nutritional value of the soil increases temporarily after burning, however, when it rains nutrients are leached and decrease (Saharjo 1995).

The effects of fire on the chemical and physical properties of forest soil will vary from none to profound depending on the soil type, the soil moisture content, the intensity and duration of fire and the timing and intensity of post fire precipitation (Chandler *et al.*, 1983). Soil properties may change in response to heat and increased exposure (Ralston & Hatchell, 1971) and burning apparently alters partitioning of nutrients between litter and soil mineral (Wells, 1971). The short-term effects of fire on nutrient availability depend on thermal effects of the fire on organic compounds, the rise in soil pH, and microbial processing of organic matter (Binkley *et al.*, 1993). The presence or absence of duff, humus and others unincorporated organic material on the forest floor and the amounts of it consumed are key in appraising soil effects (Brown & Davis, 1973).

MATERIALS AND METHOD

Research Site

Research was done from August 2001 to July 2002 in peat land in the community of Pelalawan Village, Pelalawan sub-district, Pelalawan district, Riau Province. The site is located at 102°00' E - 102°28' E and 00°10' N - 00°40' N.

A vegetation analysis showed that the research site was dominated by shrubs and ferns such as *Cyperus halpan*, *Imperata cylindrica*, *Gleichenia linearis*, *Melastoma malabathricum*, *Stenochlaena palustris*, *Erechistes valeriantnifolia* and

Nephorlepis flaccigera. Another vegetation found was *Shorea macrophylla*, *Macaranga pruinosa*, *Ficus sundaica*, *Stenochlaena palustris*, *Parastemon uruphyllus*, *Baccaurea pendula*, *Nephorlepis flaccigera* and *Gleichenia linearis*.

The site has a tropical climate with annual rainfall between 2500-3000 mm and daily temperature fluxes from 22 °C to 31 °C. According to data collected by the Meteorological and Geophysical Agency, Ministry of Transportation, annual rainfall in the between January-December 2001 at the site was 3794.5 mm, with 86 rainy days.

Based on survey results, an explanatory booklet of the land unit and a soil map of the Solok and Pekanbaru sheet, Sumatra (Hikmatullah *et al.*, 1990), it is clear that Pelalawan district is dominated by peat, including a physiographical group of peat domes. 97.1 % of the site was located on a 0-8 % slope, while the rest was on a slope of 8-15 %. The site is located less than 10 m above the sea level (an average of 2-6 m).

All sites covered by peat consisted of three different peat decomposition types namely sapric, hemic and fibric. Fibric has a slow rate of decomposition and low humus that results in very low nutrition protection capacity. Due to the lack of humic materials fibric is a poor media for agriculture. Fibric peat also has a high porosity, hence it is hard to protect from water penetration. Hemic peat has a moderate rate of decomposition and consists of several humic materials, hence it is better in nutrition protection capacity than fibric peat. Hemic peat is a good media for an agriculture, as long as the peat maintains a high content of humic materials. Sapric peat, or mature peat, has a high content of humus and also has a very good ability in mineral protecting. Peat land acidity in the site was very acidic: pH ranged between 3.0-3.7.

Classifying peat as sapric, hemic or fibric was conducted with laboratory analysis and consultation with a peat map made by PT. Riau Andalan Pulp and Paper (PT. RAPP). For the laboratory analysis, a liquid color test in a Na-pyrophosphate was used by dipping a filter paper wetted with Na-pyrophosphate 1.25 cm into the peat. . The color observed at the end of the filter was cross-referenced with the Munsell book to determine the Pyrophosphate Index (PI), which is a *value* number minus a *chrome* number with different meaning: $PI \geq 5$ means fibric, $PI = 4$ means hemic and $PI \leq 3$ means sapric (USDA, 1975).

Sampling Data

To reach the study objectives, research was conducted in the field and laboratory. Three plots, with an area of 400 m² (20 m X 20 m) each, were established at a hemic site, named hemic 1, 2 and 3. To protect from heat penetration during burning, a canal 1-m deep and 1-m wide was established surrounding the plot.

Before slashing and burning was conducted, environmental condition measurements, fuel characterization and peat characterization, peat chemical and physical properties measurements were done. Following those activity slashing was conducted after big logs (diameter more than 10 cm) were removed from the plot. Slashed logs and branches were separated uniformly through the plot. During the slashing period (drying process) fuel was characterized at different time measurements, accompanied by environmental condition monitoring, such as temperature, relative humidity and wind speed.

Following 3 weeks of drying, the plot was burnt using the ring method (burning method where burners move to create a circle that results in the fires finishing at the center of circle they made). During burning, fire behavior (rate of the spread of fire, flame length, and flame temperature) was monitored by a video camera (Sony CCD-TRV 45 NTSC, Japan). Burning was done in the afternoon from 1:00 to 5:00 p.m. using a torch made from bamboo filled with gasoline.

Activities conducted before burning

Three sub - plots 2 m² (2 m x 1 m) in all the plots of 400 m² of the hemic peat type was established in order to measure fuel characteristics such as fuel moisture, fuel bed depth, and fuel load. Three samples of 100 g each of materials found in the subplots (litter, leaves, branches, and logs) were taken and used as samples for moisture content measurements. Samples were put in the oven and dried for 48 hours at 75 °C. Fuel moisture content was estimated using dry weight measurements. Fuel load was estimated after noting the amount of plants materials both alive and dead found in the subplot. Fuel bed depth was calculated as the average height of the associated living and dead plant materials of various sizes and shapes in the subplots.

Three random peat samples up to 1 kg with 10-cm depth were taken before burning. Peat samples were collected in plastic containers and analyzed in the laboratory. Soil chemical properties analyzed were: pH (H₂O), organic-C, available phosphorus, exchangeable cations: calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), base saturation and cation exchange capacity (CEC).

Three random peat samples at 0-20 cm depth were taken before burning. Peat samples were collected using a copper cylinder (diameter 10-cm) in order to allow the samples to retain their natural characteristics in laboratory analysis. Peat physical properties analyzed were: bulk density (g cm^{-3}), porosity (%), water holding capacity (%), and permeability (cm hr^{-1}).

Flame temperature at 0 cm and 1 cm under the peat surface was measured using a data logger (Campbell Scientific Inc, model No. CR 10 X). Thermocouple temperature sensors were placed in the subplots at two locations.

Fire spread rate was calculated as the average distance perpendicular to the moving flame front per minute, using a stopwatch and the video camera recording.

It was very difficult to measure the average height of the flame directly so the flame height was calculated by observing the video camera recording.

Activities conducted after burning

Fuel left in the plot was measured by establishing 5 sub-plots of 1 m^2 in each plot. The fuel remaining in the plot was weighted and checked. Soon, after burning, penetration heat depth was measured by digging into 5 sub-plot of 400 cm^2 in each the plot until 30 cm depth.

Fire intensity was calculated using Byram's equation (Chandler *et al.*, 1983), and $\text{FI} = 273 (\text{h})^{2.17}$, where FI is fire intensity (kW/m) and h is flame height (m).

Three random peat samples up to 1 kg with 10-cm depth were taken immediately, 3 months and 6 months after burning. Peat samples were collected in plastic containers. Soil chemical properties analyzed were: pH (H_2O), C-organic (Walkley and Black method), available phosphorus (Bray I method), exchangeable cations (calcium (Ca), magnesium (Mg), potassium (K), sodium (Na)), base saturation and cation exchange capacity (CEC).

Three random peat samples at 0-20 cm depth were taken immediately, 3 months and 6 months after burning. Peat samples were collected using a copper cylinder (diameter 10-cm) to allow the samples to retain their natural characteristics for laboratory analysis. Peat physical properties analyzed were: bulk density (g cm^{-3}), porosity (%), water holding capacity (%), and permeability (cm hr^{-1}).

These soil chemical and physical properties were analyzed at the Laboratory of Soil science, Faculty of Agriculture, Bogor Agricultural University, Indonesia.

Data analysis

A completely random design of variance was used to test for differences among subplots, based on the following model (Steel & Torrie, 1981):

$$Y_{mn} = U + T_m + E_{mn}$$

Where,

Y_{mn} = fuel and fire behavior parameter at m subplot in n replication

U = mean of the treatment population sampled

T_m = treatment (slashing, drying, burning)

E_{mn} = random component

To detect significant difference of fuel and fire behavior parameters among subplots ($p \leq 0.05$), the Duncan test was used (Steel and Torrie 1981).

RESULTS

Beach characteristics

Before burning, it was found that peat depth varied from 182.0 to 188.3 cm; and fuel bed depth varied from 71.8 to 108.4 cm. Total fuel load was found to vary from 39.5 to 51.8 ton ha^{-1} and consisted of litter that varied from 20.7 to 24.7 ton ha^{-1} and branches from 18.8 to 27.2 ton ha^{-1} . Moisture content varied from 10.2 to 12.4 % for leaves; branches from 19.4 to 24.5 %; and peat surface from 74.2 to 81.8 % (Table 1).

Bulk density varied from 0.1 to 0.6 g cm^{-3} ; porosity from 84.1 to 88.6 %, water holding capacity from 25.2 to 33.4 % and permeability from 6.6 to 25.2 cm hr^{-1} (Table 2). Peat pH before burning ranged from 3.2 to 3.6; organic-C from 46.0 to 51.7 %; nitrogen from 1.1 to 1.7 %, phosphorus from 12.4 to 28.2 ppm; calcium from 2.3 to 5.4 me /100 g peat; magnesium from 1.6 to

Table 1. Weather conditions and fire behavior parameters during burning

Parameter	Hemic 1	Hemic 2	Hemic 3
Weather Condition			
Temperature (°C)	36	39	38
Relative Humidity (%)	55	48	49
Wind speed (m/sec.)	0.41	0.9	1.07
Fire behavior			
Fuel load (ton ha ⁻¹)			
Litter	20.7±6.5a*	24.7±3.2b	21.7±2.6a
Branches	18.8±1.6a	27.2±2.6c	22.0±4.0b
Total	39.5±8.0a	51.8±5.7c	43.7±3.2b
Peat depth (cm)	182.0±2.0a	188.3±1.2b	187.7±1.5c
Fuel bed depth (cm)	71.8±4.3a	101.6±9.1b	108.4±3.3c
Fuel moisture (%)			
Leaves	11.9±3.5a	12.4±1.9a	10.2±4.7a
Branches	21.6±6.7a	24.5±7.0b	19.4±5.9a
Peat surface	81.8±1.5b	77.2±1.4a	74.2±0.2a
Flame height (m)	2.9±0.3b	3.6±0.4a	3.4±0.3a
Fire int. (kW m ⁻¹)	2949.9±547.3b	5050.9±1052.4c	2552.3±977.2a
R. of the spr. (m mnt ⁻¹)	1.1±0.2a	1.9±0.2b	2.5±0.4c
1 cm below ground	100	130	120
Ground	900	1100	1000

* Means are significantly different among hemic categories when standard errors are followed by different letters (p ≤ 0.05)

Table 2. Peat physical properties following burning in Hemic 1, 2, and 3

Parameters	Before burning	Three months after burning	Six months after burning
HEMIC 1			
Bulk density (g cm ⁻³)	0.2±0.1a*	0.2±0.0a	0.2±0.0a
Bulk density (g cm ⁻³)	84.5±3.2a	85.7±3.1a	84.1±0.4a
Water holding capacity (%)	28.7±6.3a	32.8±3.9b	28.7±2.0a
Permeability (cm hr ⁻¹)	6.6±0	6.1±2.9a	6.2±3.3a
HEMIC 2			
Bulk density (g cm ⁻³)	0.2±0.0a	0.2±0.0a	0.2±0.0a
Bulk density (g cm ⁻³)	88.6±2.6a	85.9±2.9a	86.7±0.4a
Water holding capacity (%)	20.4±2.7a	30.6±2.4c	28.8±1.3bc
Permeability (cm hr ⁻¹)	12.5±2.2c	0.2±0.0a	4.9±2.2b
HEMIC 3			
Bulk density (g cm ⁻³)	0.2±0.0a	0.2±0.0a	0.2±0.0a
Bulk density (g cm ⁻³)	84.1±2.5a	87.9±1.4a	87.1±0.0a
Water holding capacity (%)	24.6±3.0a	32.8±2.0c	30.1±5.4bc
Permeability (cm hr ⁻¹)	25.2±17.3c	3.6±2.3b	0.04±0.0a

* Means are significantly different among sampling times when standard errors are followed by different letters (p ≤ 0.05)

2.8 me /100 g; potassium from 0.6 to 0.9 me /100 g; sodium from 1.0 to 1.5 me /100 g; base saturation from 5.6 to 10.8 % and CEC from 82.4 to 129.3 me /100 g (Table 3).

Following burning (Table 1), it was found that to the variation in high fire intensity of 2552.3 kW/m (Hemic 3) to 5050.9 kW/m (Hemic 2) caused peat burned depth to vary from 6 cm (hemic 3) to 12.6 cm (Hemic 2). High fire intensity was predicted due to the high flames that ranged from 2.9 m (Hemic 1) to 3.6 m (Hemic 2) which are related to their high flame

Table 3. Peat chemical properties following burning in Hemic 1, 2, and 3

Parameters Before	Burning	Three months after burning	Six months after burning
HEMIC 1			
pH	3.2-3.6	3.2-3.3	3.5-3.7
organic-C (%)	51.3±1.4c*	40.9±10.8a	45.1±2.7b
Nitrogen (%)	1.3±0.3b	0.4±0.1a	0.5±0.0a
Phosphorus (ppm)	12.4±7.6b	9.3±2.9a	8.2±0.8a
Calcium (me/100 g peat)	3.9±1.1c	1.2±0.3a	2.1±0.3b
Magnesium (me/100 g peat)	2.2±0.7b	0.8±0.3a	0.8±0.1a
Potassium (me/100 g peat)	0.8±0.1b	0.4±0.1a	0.3±0.1a
Sodium (me/100 g peat)	1.5±0.8b	0.3±0.0a	0.3±0.1a
Base saturation (%)	10.8±3.2b	7.2±1.5a	9.9±1.0b
CEC (me/100 g peat)	82.4±24.2b	36.1±1.5a	35.4±1.0a
HEMIC 2			
pH	3.3-3.5	3.2-3.3	3.5-3.8
organic-C (%)	46.0±0.9a	48.6±0.6a	47.3±1.2a
Nitrogen (%)	1.1±0.1b	0.5±0.1a	0.5±0.1a
Phosphorus (ppm)	19.9±1.9c	5.9±0.5a	9.9±0.6b
Calcium (me/100 g peat)	2.3±0.8a	2.8±0.9a	2.3±0.5a
Magnesium (me/100 g peat)	1.6±0.5c	1.3±0.3b	0.9±0.1a
Potassium (me/100 g peat)	0.6±0.2c	0.5±0.1b	0.4±0.0a
Sodium (me/100 g peat)	1.0±0.4c	0.6±0.0b	0.4±0.0a
Base saturation (%)	5.6±2.1a	11.4±2.9b	10.1±1.6b
CEC (me/100 g peat)	99.5±6.3c	45.1±0.6b	39.6±1.7a
HEMIC 3			
pH	3.3-3.5	3.4-3.8	3.7-4.2
organic-C (%)	51.7±0.4a	49.8±3.3a	49.0±3.6a
Nitrogen (%)	1.7±0.3b	0.5±0.0a	0.5±0.0a
Phosphorus (ppm)	28.2±1.0c	5.9±3.3a	17.0±8.5b
Calcium (me/100 g peat)	5.4±3.1c	2.2±0.1a	3.4±0.9b
Magnesium (me/100 g peat)	2.8±0.9	1.4±0.2a	1.3±0.2a
Potassium (me/100 g peat)	0.9±0.2c	0.7±0.1b	0.5±0.2a
Sodium (me/100 g peat)	1.5±0.8c	0.6±0.0b	0.4±0.1a
Base saturation (%)	8.0±1.3a	7.5±0.5a	13.2±3.7b
CEC (me/100 g peat)	129.2±35.5c	63.9±3.0b	43.2±5.3a

* Means are significantly different among sampling times when standard errors are followed by different letters ($p \leq 0.05$)

temperatures, resulting in burning that varied from 900 °C (Hemic 1) to 1100 °C (Hemic 2) on the ground and at 1-cm below ground, from 100 °C (Hemic 1) to 130 °C (Hemic 2).

It was found that the high fire intensity during burning had significant impacts on the changes in chemical and physical properties of hemic peat (Table 2 and 3). Three months following burning, it was found that only base saturation in hemic (2 and 3) increased significantly, while after six months only base saturation (hemic 2 and 3) increased compared to the before burning conditions (Table 3). As for physical properties, it was found also that at three and six months following burning, only water holding capacity increased significantly compared to the before burning conditions.

DISCUSSION

Our results show that at three and six months following burning, only base saturation in hemic 2 and 3 increased significantly compared to the before burning conditions, while other parameters decreased or were unchanged. A decrease in most

nutrients, both at three and six months following burning, was predicted because nutrients released into the ground through ash can be leached by surface run off after a rainfall. In this case, there was precipitation a couple of weeks following burning (peat samples for physical property analysis could not be taken due to the research site having been covered with water). Decreases in Ca, Mg, Na, and K following burning may be caused by leaching and run off (Toky & Ramakhrisnan, 1981; Saharjo & Makhrawie, 1998) and surface run off and sediments in the run off can carry the elements in the ash and soil down stream (DeBano & Conrad, 1976). The worst condition of site that occurred during the first six months following burning is believed to have been caused by a high fire intensity, high temperature fire that burned to depths ranging from 6 to 12.6 cm. Heat produced by combustion can be transferred to the duff or to the mineral soil surface; heat radiated downward in the soil is the driving mechanism for increasing soil temperatures in the soil, the temperature increases initiate a wide range of responses in the soil's physical, chemical and biological systems (Debano *et al.*, 1998). The burned peat could not return back to its pre-burn condition, (Table 1) because peat has irreversible characteristics: burned peat was leached due to surface run off.

Fire--destroyed peat affects both the soil's chemical and physical properties. Research results show that at three and six months following burning, only water holding capacity tended to increase significantly, while other parameters tended to decrease or were unchanged. The effect of fire on the chemical and physical properties of forest soil will vary significantly depending on the type of soil, the moisture content of soil, the intensity and duration of fire, and the timing and intensity of post fire precipitation (Chandler *et al.*, 1983) and also soil properties may change in response to heat and increased exposure (Ralston & Hatchell, 1971). The decreasing in the permeability of hemic 2 and 3 at three and six months following burning may be a result of its lack of protection from the beating action of raindrops dispersing and then compacting the peatsoil (Fuller *et al.*, 1955). Besides destroying the litter layer, heat also kills insects and other microorganisms, which have directly impact to the soil resulting in a reduction of soil porosity (Kittredge, 1938). This can be found also at the burned site.

CONCLUSION

High fire intensity during burning and flame height from 2.9 to 3.6 m caused 39.5 to 51.8 ton ha⁻¹ of fuel load to be burnt and resulted in 2552.3 to 5050.9 kW/m of heat, thus negatively impacting the peat by significantly affecting the chemical and physical properties of hemic peat.

At three and six months following burning, it was found that only the chemical property of base saturation (hemic 2 and 3) and only the physical property of water holding capacity increased significantly compared to the peat's pre-burn condition.

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