Wetlands Ecology and Management **13:** 105–110, 2005.

Controlled burning in peat lands owned by small farmers: a case study in land preparation

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Received 12 February 2003; accepted in revised form 1 September 2003

Key words: Fire, Land preparation, Peat, Small-holder, Smoke

Abstract

The 1997/1998 forest fires in Indonesia resulted in the destruction of at least 10 million ha of forests and non-forestlands and the release of more than 2.6 G tons of carbon. These fires made Indonesia one of the largest contributors of greenhouse gases in the world. It is now recognized that about 80–90% of the fires came from agricultural and industrial plantation estates using fire for land preparation activities. Estate oil palm development accounted for the majority of the fires, particularly in Riau. At least 176 companies accredited with the Indonesian Forestry and Estate Crops Department caused the fires in 1997/1998. More than 50 companies in 1999 and 100 companies in 2001 were identified to be still using fire in land preparation activities. To make matters worse, the use of fire in land clearing is also prevalent among many small-holder farmers as a traditional means of land preparation. Since 2000, some companies using fire for land preparation have been taken to court and been punished. Meanwhile, shifting cultivators still have the possibility of using fire as long as the impact is not so bad. In order to understand the behavior and characteristics of fire in land preparation by small-holder farmers, several peat fire experiments were conducted. The experiments showed that high flame temperature and intensity result from high fuel loads. Such information is important in order to evaluate land preparation practices with the use of fire, to determine restoration methods, and to recommend appropriate policy reforms for small-holder farmers.

Introduction

Human activity is the major agent causing stratospheric ozone depletion, global warming, deforestation, acid precipitation, extinction of species, and other changes that have not yet become apparent (Levine 1996). These changes are caused, and significantly enhanced, by biomass burning. Biomass burning is the burning of the world's living and dead vegetation, including grasslands, forests, and agricultural lands following harvest for land clearing and land-use change (Levine 1996). Biomass burning is a significant global source of gaseous and particulate emissions to the atmosphere.

Fire risk is increased dramatically by the conversion of forests to rubber and oil palm plantations, and by the logging of natural forests, which opens the canopy and dries out the ground cover. Plantations are drier, and trees are move evenly spaced than natural tropical moist forests, thus increasing opportunities for fire to spread. Evidence also suggests that fires burn most easily in secondary forests that have already been disturbed during (frequently illegal) timber operations. Selective logging destroys much of the undergrowth and the closed canopy that previously reduced the likelihood and impact of forest fires in natural forests (EEPSEA and WWF 1998). Unfortunately, small land holders have been blamed for causing most of the smoke releases (Fagi et al. 1997). Traditional slash-and-burn has been used successfully for centuries and is an integral part of farming and land clearing techniques in the tropics. The answer to controlling smoke and haze that fires produce is not to ban burning outright but to regulate it, expand technological options, and make policy changes that will prevent another environmental disaster the next time there is a long dry season (Fagi et al. 1997).

A large fire in 1994 destroyed 5.11 million ha of forest, causing the Indonesian government to declare a no burn policy in June 1995. Unfortunately, the policy has not worked well because it has not been supported by field guidelines or practical implementation and there are no clear sanctions to be applied for companies that do not obey the policy. In 1997/1998 about 10 million ha of forest in Indonesia were destroyed, mostly by arson.

In early 2000 the government again pushed the idea of a no burn policy accompanied by law enforcement to minimize smoke production during the dry season. This was mainly applied towards large companies as it was difficult to apply to small farmers. To solve the small farmer problem, controlled burning through fuel management and modifications in burning techniques may be possible solutions to minimize the impact to the environment.

Methods

Research was conducted from August 2001 until July 2002 in peatland belonging to the Pelalawan village, Pelalawan sub-district, Pelalawan district, Riau Province, Indonesia (102°00′–102°28′E and 00°10′–00°40′N). Total peat area in this site was 5362.5 ha. The research site was dominated by shrubs and ferns such as *Shorea macrophylla*, *Macaranga pruinosa*, *Ficus sundaica*, *Stenochlaena palustris*, *Parastemon uruphyllus*, *Baccaurea pendula*, *Nephrolepis flaccigera*, and *Gleinchenia linearis*. The area has a tropical climate with annual rainfall ranging between 2500–3000 mm and daily temperatures between 22 °C and 31 °C. According to data from the Meteorological and Geophysical Agency, Ministry of Transportation, rainfall between January–December 2001 was 3794.5 mm with 86 rainy days.

There are three different kinds of peat covering the study site: fibric, hemic, and sapric. The fibric peat type has a low level of decomposition, low humus, and very low nutrition protection capacity. Due to these factors, fibric peat is a poor media for agricultural activity. Fibric peats also possess a high porosity which allows rapid water penetration. Hemic peat has a moderate level of decomposition and consists of several humic materials giving it better nutrition protection capacity than fibric peat. Hemic peat provides a good media for agricultural activity as long as the peat has a high content of humic materials. Sapric or mature peat has a high content of humus and also is very good in mineral protecting. Peat land acidity in the site was very acid, with a pH range between 3.0–3.7.

Activities conducted before burning

Four plots of 0.04 ha (20 m × 20 m) each were established in sapric peat. Each plot was surrounded by 1-m wide and 1.5-m deep canal. Water in the canal could be controlled and used to saturate the peat when burning was conducted.

All vegetation found in the plots (shrubs, seedlings, saplings, poles, and trees) was cut down (slashed) and spread out. Logs with diameters of more than 10 cm were pushed out of the plots. Following slashing, the material was allowed to dry for 3 weeks as it is usually done by small farmers in Riau.

Three 2 m^2 (2-m × 1-m) subplots were chosen in each plot. Living and dead plant material in the subplots was collected by destructive sampling, dried, and weighed. Fuel load on a dry weight basis was estimated after slashing and before burning.

Three 100 g samples of each of the materials (litter, leaves, branches, and logs) found in each subplot were taken and used for moisture content measurement. Samples were dried for 48 hours at 75 °C (Clar and Chatten 1954). Fuel moisture content was estimated through dry weight basis. Fuel bed depth was measured by the average height of dried fuel spread out in the subplot. Measurements were taken at five locations in each subplot.

Activities conducted during burning

Burning was conducted using the circle (ring) method. In this method, four burners stand at four positions (sides of plot) where they can see each other. Burning started with one command, and depending on wind condition, movement of the burners was clockwise or opposite. All plots were burnt using the same method but at different times, ranging from 11:22 a.m. to 15:55 p.m. The source of fire was bamboo filled with gasoline. Fire spread naturally in the plots. Flame temperature at 0 m above the soil and 1 cm below the ground were measured using data loggers in each sub-plot. The data loggers were connected to a laptop computer, allowing monitoring of flame temperature during burning. Rate of spread of the fire was measured (10 measurements per plot) using a stop watch and tape. Flame length was very difficult to measure directly, thus it was measured indirectly using scaled bamboo and a camera. Ten images from each plot were used to calculate flame height.

Activities conducted following burning

Burnt fuel percentage was estimated by identifying and collecting and segregating burnt materials based on their fuel characteristics (litter, branches, and logs) in each sub-plot in all the plots soon after burning. Peat destruction was estimated at five locations in every sub-plot through heat penetration impact (evidenced by blackened peat). Fire intensity was calculated using Byram's equation (Chandler et al. 1983):

$$\mathrm{FI} = 273(\mathrm{h})^{2.17},$$

where FI is fire intensity (kW m^{-1}) and h is flame length (m).

Statistical analysis

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

$$\mathrm{Ymn} = \mathrm{U} + \mathrm{Tm} + \mathrm{Emn}$$

where Ymn = fuel and fire behavior parameter at m subplot in n replication, U = mean of the treatment population sampled, Tm = treatment (slashing, drying, burning), and Emn = random component.

Table 1. Fuel load after slashing (ton ha^{-1}).

Plot	Litter	Branches	Total
1	31.83 (±9.78)a	51.67 (±3.82)a	83.50 (±13.50)a
2	33.67 (±15.33)a	36.50 (±4.58)a	70.17 (±16.97)a
3	46.33 (±29.24)a	37.50 (±24.02)a	83.83 (±9.46)a
4	36.50 (±14.26)a	41.60 (±10.22)a	78.10 (± 4.70)a

Means are significantly different when standard errors are followed by different letters ($p \leq 0.05$).

To detect significant differences of fuel and fire behavior parameters among sub-plots ($p \leq 0.05$), the *t*-test was used (Steel and Torrie 1981).

Results

Fuel characteristics

After slashing, Plot 3 contained the highest fuel load (83.83 ton ha^{-1}), while Plot 2 contained the least (70.17 ton ha^{-1}; Table 1). Fuel moisture content of litter ranged from 23.65% in Plot 2 to 39.80% in Plot 4 (Table 2), while fuel moisture content of branches ranged from 26.12% in Plot 3 to 36.18% in Plot 4. Fuel bed depth ranged between 82.8 cm in Plot 2 to 98.4 cm in Plot 4 (Table 3).

Three weeks of drying decreased fuel load of branches significantly in all plots (Table 4). The highest fuel load was found in Plot 1 (61.67 ton ha^{-1}) and the lowest in Plot 4 (55.0 ton ha^{-1}). Litter moisture content ranged from 7.50% in Plot 3 to 10.64% in Plot 1 (Table 5). Overall, three weeks drying reduced the fuel load 21% to 30%.

Fire behavior

Rate of spread of fire varied from 0.47 m min^{-1} in Plot 1 to 1.11 m min^{-1} in Plot 3 (Table 6). The rate of the spread was a reflection of flame length, which ranged from 1.56 m in Plot 1 to 3.09 m in Plot 3 (Table 6).

Highest flame temperature at the ground (peat surface) during burning was 1000 °C in Plot 3 and the lowest was 800 °C in Plot 1. At 1 cm below the peat surface, the highest temperature reached was 95 °C in Plot 3 and the lowest was 70 °C in Plot 1 (Table 6). Fire intensity was highest in Plot 3 with 1830.55 kW m^{-1} and the lowest in Plot 1 with 792.95 kW m^{-1} (Table 6).

Table 2. Fuel moisture content after slashing (%).

Plot	Dry leaves	Wet leaves	Wet branches	Dead branches
1	32.30 (±6.63)a	54.27 (±2.63)a	54.32 (±6.14)a	27.38 (±9.17)a
2	23.65 (±5.67)b	53.06 (±27.24)a	54.03 (±24.58)a	30.38 (±16.29)a
3	25.97 (±18.37)a	48.28 (±14.09)a	51.68 (±17.07)a	26.12 (±6.17)a
4	39.80 (±20.30)b	54.0 (±9.02)a	53.46 (±10.94)a	36.18 (±10.17)a

Means are significantly different when standard errors are followed by different letters ($p \leq 0.05$).

Table 3. Fuel bed depth in the subplot.

Plot	Depth (cm)
1	96.0 (±45.9)a
2	82.8 (±21.3)bc
3	98.4 (±47.3)c
4	93.4 (±55.15)b

Means are significantly different when standard errors are followed by different letters ($p \leq 0.05$).

Table 4. Fuel load before burning (ton ha^{-1}).

Plot	Litter	Branches	Total
1	20.83 (±1.44)a	40.83 (±23.22)a	61.67 (±22.41)a
2	23.30 (±7.63)a	32.33 (±8.74)a	55.67 (±14.01)a
3	22.50 (±2.50)a	36.37 (±13.77)a	59.17 (±11.25)a
4	20.0 (±2.5)a	35.60 (±6.61)a	55.0 (±9.0)a

Means are significantly different when standard errors are followed by different letters ($p \leq 0.05$).

Burnt litter varied from 50% in Plot 1 to 90% in Plot 3, while burnt branches varied from 40% in Plot 1 to 75% in Plot 3 (Table 7). The depth and size of burnt peat varied in every plot. The deepest burnt peat surface among the plots was 31.87 cm in Plot 2 with an area of 7 m^2, representing 1.75% of the area burnt. The shallowest was 12.72 cm in Plot 4 with an area of 22 m^2, representing 5.5% of the area burnt (Table 8).

Discussion

Fuel characteristics

The amount of fuel moisture change is closely correlated to daily temperature changes rather than with fluctuations in humidity or soil moisture (Chandler et al. 1983). Decreasing fuel load, especially before burning, is very important in making fire spread faster and relatively under more control. Fine fuels (litter) burn best when loosely packed, while coarse fuels (branches) burn best when packed more tightly (Burgan 1987). Decreasing of fuel load through log selection followed by drying (three weeks in this research) is one option for decreasing the possibility of high intensity fires and minimizing the negative impact to the environment (i.e. peat destruction).

Table 5. Fuel moisture content before burning (%).

Plot	Litter	Branches
1	10.64 (±1.15)a	14.09 (±3.40)a
2	8.67 (±1.56)a	14.49 (± 4.44)a
3	7.50 (±2.21)a	13.87 (±4.37)a
4	8.84 (±1.72)a	13.36 (±2.89)a

Means are significantly different when standard errors are followed by different letters ($p \leq 0.05$).

Fire behavior

During this field experiment, weather conditions in each plot were not significantly different except for wind. Air temperature varied from 35 °C to 39 °C, relative humidity ranged from 49% to 55%, and wind speed varied from 0.41 m min^{-1} in Plot 1 to 1.09 m min^{-1} in Plot 2. Wind speed was very important during burning because all the plots have 0% slope, and wind is one of the most variable and most important weather factors in influencing forest fires (Chandler et al. 1983).

Although the properties of the individual fuel particles have a direct influence on ignition and combustion, the behavior of an established fire depends principally on fuel bed depth characteristics (Chandler et al. 1983). Peat destruction due to heat penetration depends on how much fuel is present and peat characteristics, especially moisture content. Peat destruction was prevented through high peat moisture content resulting from the water from the canal surrounding the burn area. Another

Table 6. Weather condition and fire behavior parameters during burning.

Parameter	Plot 1	Plot 2	Plot 3	Plot 4
Weather condition				
Temperature (°C)	38	38	39	35
Relative humidity (%)	55	50	49	52
Wind speed (m/sec.)	0.41	1.09	1.07	0.63
Fire behavior				
Fuel load (ton ha^{-1})	61.67 (±22.41)a	55.67 (±14.01)a	59.17 (±11.25)a	55.0 (±9.0)a
Fuel moisture (%)				
Leaves	10.64 (±1.15)a	8.67 (±1.56)a	7.53 (±2.21)a	8.84 (±1.72)a
Branches	14.09 (±3.40)a	14.49 (±4.44)a	13.87 (±4.37)a	13.36 (±2.89)a
Flame length (m)	1.56 (±0.52)a	2.11 (±0.26)ab	3.09 (±1.07)b	1.94 (±0.85)a
Fire int. (kW m^{-1})	792.95 (±572.39)a	1401.6 (±355.2)ab	1830.55 (±634.73)b	1379.0 (±1103.6)ab
R.of the spr.(m min^{-1})	0.47 (±0.15)a	0.99 (±0.26)ab	1.11 (±0.32)b	0.98 (±0.29)ab
Flame temp. (°C)				
1 cm below ground	70	90	95	80
Ground	800	985	1000	900
Slope (%)	0	0	0	0
Plot size (ha)	0.04	0.04	0.04	0.04
Duration (min)	22.13	21.30	28.10	19.00
Burning time	11.22 a.m	13.43 p.m	14.54 p.m	15.55 p.m

Means are significantly different when standard errors are followed by different letters ($p \leq 0.05$).

Table 7. Burnt fuel percentage (%).

Plot	Litter	Branches
1	50	45
2	80	60
3	90	75
4	78	50

Table 8. Burnt peat depth and size of burned area.

Plot	Depth (cm)	Burnt size (m^2)	Percentage
1	18	12	3
2	31.87	7	1.75
3	15.44	17	4.25
4	12.72	22	5.5

important factor is the drying process which determines smoke production during burning and the time needed for burning available fuels. In order to let the fire spread naturally and minimize peat destruction, it is recommended to leave only small diameter (<5 cm) branches for burning and to make sure that materials are dried to no more than 10% moisture content. Without these changes it is difficult to say that land preparation can be done with less impact.

Conclusions

Controlled burning can be used as one method of land preparation by small farmers where they cannot live without fire. Low impacts to peatlands can be achieved by using practical techniques before and during burning. Before burning activities include slashing and drying. Drying will reduce fuel moisture content which makes the rate of the spread of fire relatively uniform and limits the occurrence of wildfires. Another important factor is using water canals to protect the peat from penetration heat which causes peat destruction.

Acknowledgements

Special thanks to the Environmental Department of PT. Riau Andalan Pulp and Paper (PT.RAPP) which funded the research.

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