BIODIVERSITAS
Volume 11, Number 1, January 2010
Pages: 40-45

ISSN: 1412-033X (printed edition)
ISSN: 2085-4722 (electronic)
DOI: 10.13057/biodiv/d110109

Fuel characteristics and trace gases produced through biomass burning

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Manuscript received: 10 November 2009. Revision accepted: 30 December 2009.

ABSTRACT

Saharjo BH, Sudo S, Yonemura S, Tsuruta H (2010) Fuel characteristics and trace gases produced through biomass burning. Biodiversitas 11: 40-45. Indonesian 1997/1998 forest fires resulted in forest destruction totally 10 million ha with cost damaged about US$ 10 billion, where more than 1 Gt CO_2 has been released during the fire episode and elevating Indonesia to one of the largest polluters of carbon in the world where 22% of world's carbon dioxide produced. It has been found that 80-90% of the fire comes from estate crops and industrial forest plantation area belongs to the companies which using fire illegally for the land preparation. Because using fire is cheap, easy and quick and also support the companies purpose in achieving yearly planted area target. Forest management and land use practices in Sumatra and Kalimantan have evolved very rapidly over the past three decades. Poor logging practices resulted in large amounts of waste will left in the forest, greatly elevating fire hazard. Failure by the government and concessionaires to protect logged forests and close old logging roads led to and invasion of the forest by agricultural settlers whose land clearances practices increased the risk of fire. Several field experiments had been done in order to know the quality and the quantity of trace produced during biomass burning in peat grass, peat soil and alang-alang grassland located in South Sumatra, Indonesia. Result of research show that different characteristics of fuel burned will have the different level also in trace gasses produced. Peat grass with higher fuel load burned produce more trace gasses compared to alang-alang grassland and peat soil.

Key words: peat soil, peat grass, alang-alang, biomass burning, trace gas.

INTRODUCTION

In 1997/1998 forest fires at least 20 million of Indonesian peoples were directly and indirectly affected by fire. Black smokes contain many air pollutants: CO, CO_2, SO_2, $NO_{(x)}$ and NH_4 and bacteria such as Streptococcus cause many diseases such as diarrhea, pneumonia, bronchitis and brain disturbance. Thousand of people in Riau, Jambi, South Sumatra, and Central, West and East Kalimantan were hospitalized for medical treatment. Black smoke that continued for at least two months in southern Sumatra at which time the lack of sunshine reduced food production and caused many peoples to seek emergency food sources. Hundreds of peoples also died in Papua (Irian Jaya) because the transportation of food and other supplies could not reach their areas due to smoke.

Biomass burning is the burning of living and dead vegetation, including grasslands, forests and agricultural lands following the harvest for land clearing and land-use change. Biomass burning is not restricted to one geographical region, but is rather a truly global phenomenon (Levine 1996). Biomass burning is a significant global source of gaseous and particulate emissions to the atmosphere. Gases produced by biomass burning include: (i) GHG gases, CO_2, CH_4 and N_2O that lead to global warming, (ii) chemically active gases, NO, CO, CH_4 and NMHCs, which lead to the photochemical production of ozone (O_3) in the troposphere, and (iii) CH_3Cl, and CH_3Br which lead to the chemical destruction of ozone in the stratosphere (Levine 1985). Direct effects on atmospheric composition and chemistry and climate, biomass burning perturbs other components and processes in the earth's system, including (i) the biogeochemical cycling of nitrogen (N_2O and NO) and carbon (CO_2, CO and CH_4) gases from the biosphere to the atmosphere, (ii) water run-off and evaporation, and hence, impacts the hydrological cycle, (iii) the reflectivity and emissivity of the land, which in turn changes the radiative properties of the land and hence, impacts climate, and (iv) the stability of ecosystems which in turn impacts biological diversity.

Fire is a significant source of gases and particulate to the atmosphere: environmentally important gases produce by fire includes carbon dioxide, carbon monoxide, methane, non-methane hydrocarbons and oxides of nitrogen. Fire also produces large amounts of small, solid particles or "particulate matter", which absorb and scatter incoming solar radiation, and hence the impact of our planet as well as provoking a variety of human health problems (Levine 1996). Fire can therefore be considered one of the local points of the multiple relationships between humans and the environmental changes in fire patterns can be taken as indicator of change in land-use patterns and overall environmental conditions (Malingreau and Gregorie 1996).

Forest fires destroy large forest areas that serve as habitat for biodiversity. They directly eliminate plants and animals and also result in forest degradation that leads to a decrease in the survival rate of the species. For example, the fires in 1997-1998 resulted in 33% population decline of the Orangutan (*Pongo pygmaeus*) in Borneo (Rijksen and Meijaard 1999). Moreover, fires in 1982-1983 in Kutai National Parks (East Kalimantan) resulted in widespread mortality of reptiles and amphibians (MacKinnon et al. 1996) and lost of fruit trees that caused the population of fruit-eating birds such hornbills declined dramatically (Nasi et al. 2002). The most severe fires in the last twenty years occurred in 1997, affecting approximately 11.7 million hectares, mostly lowland peat and swamp forests, timber plantations and agricultural areas (Tacconi 2003).

This study consisted of two parts: field experiment and laboratory experiment (analysis). First, test biomass burning was conducted at three different land type namely alang-alang or cogon (*Imperata cylindrica*) grassland, peat soil and peat grass. These land types are suspected of being responsible for much of the smoke produced during the 1997/98 fire episode in Indonesia. More than 2 Mha of peat lands were burned during the 1997/98 fires (Tacconi et al. 2006). In addition, when these vulnerable ecosystems were accounted for, Murdiyarso and Adiningsih (2007) estimate that the total carbon emissions during 1997/98 fires was 5.3 Gt CO_2.

MATERIALS AND METHODS

Research Site

Alang-alang grassland

The research in alang-alang grassland was carried out in the area belonging to the PT. Musi Hutan Persada, Barito Pacific Group, South Sumatra. The mean annual rainfall is about 2,000 mm and monthly rainfall is about 209 mm ranging from 92 mm in July to 278 mm in February. According to the Schmidt and Fergusson (1951) system, the climate of this area belongs to rainfall type A. Mean maximum air temperature in this area is 32.6°C in August, mean minimum air temperature is 22.6°C in December and mean annual relative humidity is about 85%. The soil is red yellow podsolic and the USDA soil classes are: Haplaquox, Dystropepts, Kandiudults and Haplaquox. This area has the following characteristics: Slopes < 8%, 5-125 m altitude, drainage varies from well-drained to imperfectly drained, soil mineral depth is 101-150 cm, Cation Exchange Capacity (CEC) is 4.9 - 17.9 me gr^{-1}, base saturation is 5.6-21.8%, available phosphorus is 0.4-3.2 ppm, total nitrogen is 0.11-0.20%, organic carbon is 1.09-3.51%, free salinity, and soil fertility based on Indonesian criteria is low (Hikmatullah et al. 1990). Understorey vegetation dominated by *Imperata cylindrica*, *Eupatorium pubescens, Clidemia hirta*, *Tetracera* sp, *Artocarpus anisophyllus*, *Macaranga javanica*, and *Dillenia grandifolia.*

Peat soil and peat grass

The test burn in the peat grass site was done in peat soil that (dominated by hemic peat) was located in Teluk Pulai the area which belongs to PT. SBA Wood Industry, South Sumatra. The mean annual rainfall is about 2,800 mm and monthly rainfall ranges from 70 mm in August to 365 mm in March. According to the Schmidt and Fergusson (1951) system, the climate of this area belongs to rainfall type B. Mean maximum air temperature in this area is 38.8°C in June, mean minimum air temperature is 21.2°C in January and mean annual relative humidity is about 89.9%. The peat type is hemic dominant. The area has the following characteristics: Slopes < 8%, 0-5 m altitude, drainage varies from well-drained to imperfectly drained, high salinity, peat depth is 0.5-2.5 m and soil fertility based on Indonesian criteria is low or poor (Suwarso 1997).

Measurement and Analysis

Data presented in this paper were derived from field experiments both in mineral soil (alang-alang grassland) and peat land (peat soil and peat grass).

Alang-alang grassland

Three of 3 m x 3 m plot were established in the alang-alang grassland, where 1.5 m of firebreaks established surrounded the plot. Fuel available consisted of grasses and litter. Smoke samples from the burning site were taken by using evacuated canisters. Smoke samples were taken at different phases of combustion, flaming, smoldering and glowing. Samples taken were analyzed in the Greenhouse Gas Laboratory of National Institute for Agro-Environmental Science, Tsukuba, Japan for analysis. Gasses analyzed are CO, CO_2, N_2O, CH_4, CH_3Br, CH_3Cl, and CH_3 I.

Peat soil

Three different size plots were established in the hemic site. First and second plots, 1 m x 2 m, were surrounded by a 30 cm wide and 50 cm deep canal. The third plots were 1 m x 1.5 m size. Peat moisture content was measured directly using digital moisture content thermocouple. Flame temperature was measured using data logger which the sensors (thermocouples) put in the peat surface in the plot. Logs and branches were put in the canal and fires were started using gasoline. Flame temperature was monitored for a half days following ignition. Smoke samples were taken by using portable pump which connected to the vacuum plastic. Smoke samples accumulated in vacuum plastic then transferred into the vacuum bottles. Smoke samples were taken at combustion during flaming, smoldering and glowing phases of the burn. Smoke samples that storage in the vacuum bottles were then sent to the Greenhouse Gas Laboratory of National Institute for Agro-Environmental Science, Tsukuba, Japan for analysis. Gasses analyzed are CO, CO_2, N_2O, CH_4, CH_3Br, CH_3Cl, and CH_3I.

Peat grass

Three plot of 1 m x 1 m size was established in the peat grass dominated by ferns (*Gleichenia linearis*, *Lygodium scandens*, *Nephrolepis fascigera* and *Stenochlaena palustris*). Before burning was conducted, 1 m firebreaks were established around each plot in order to prevent fire from jumping to non target areas. Burning was conducted by igniting the dead fuels within live grass community. Smoke samples were taken by using portable pump which connected to the vacuum plastic. Smoke was taken at combustion during flaming, smoldering and glowing phases of the burn. Smoke samples in the vacuum plastic then transferred to the vacuum bottle which finally sent to the Greenhouse Gas Laboratory of National Institute for Agro-Environmental Science, Tsukuba, Japan for analysis. Gasses analyzed are CO, CO_2, N_2O, CH_4, CH_3Br, CH_3Cl, and CH_3 I.

Trace gas measurement

Four kinds of gas chromatograph (GC) systems were used for whole analysis on trace gases measurement. Methane (CH_4) gas was measured by using Shimadzu GC-9A Flame Ionization detector (FID) which attached to GC with back flush system. Carbon Dioxide (CO_2) gas was measured by using Thermal Conductivity Detector (TCD) of the same column system with methane gas measurement. Carbon Monoxide (CO) gas was measured by using Trace Analytical Systems Inc. RGA3 of Reduced Gas Detector with 5 m Molecular Sieve 13X packed column system. 1 ml STP gas was injected for analysis of each above 3 gas species. For halogenated species for example: CFCs, CH_3Br, and CH_3I, Shimadzu GC-14B ECD (Electron Capture Detector) system with clyofocusing method used. CP PoraBOND Q capillary column (0.32 mm i.d. x 25 m) was used for separation. ECD was also used for N_2O analysis with three dimensional separation systems with using 3 Poapak Q (3.0 mm i.d. x 1 m) stainless steel columns. For CH_4, CO_2, CO, N_2O, standard gas were made by Nippon Sanso Industry with concentration of 2.0 ppm and 10.0 ppm for CH_4, 350 ppm and 500 ppm for CO_2, 150 ppb and 20 ppm for CO, and 300 ppb and 1 ppm for N_2O respectively. For halogenated species, standard gas measurement were made by Taiyo Toyo Sanso Industry, Japan with concentration of 100 ppt, 1.00 ppb, and 10.0 ppb for all gases containing CFC12, CFC-11, CH_3Cl, CH_3Br, CH_3I. Precision of whole measurement were within 10 percent.

Statistical analysis

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

Ymn = U + Tm + Emn

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

To detect significance difference among fuel and fire behavior parameter among subplot ($p \leq 0.05$), the Duncan test was used (Steel and Torrie 1981).

RESULTS AND DISCUSSION

Weather condition and fire behavior

Data in Table 1 show weather conditions when burnings were conducted. The peat grass site air temperature was 28-32°C which was the lowest. Relative humidity at peat soil was 60-65% which was the lowest of the site. Fuel load varied from 10 to 20 ton ha^{-1}. Fuel moisture content varied from 10% to a maximum of 70%. Flame temperature during burning was 500-600°C at the alang-alang site and at the other two sites, 700-800°C. Burning time for alang-alang grasslands was the fastest compared to other type of fuel from different land type where the 9 m^2 plot of alang-alang required less than 3 minutes for each plot.

Table 1. Weather condition and fire behavior parameter

Parameter	Land type		
	Alang-alang	Peat soil	Peat grass
Air temperature (°C)	33-35	32-33	28-32
Relative humidity (%)	70-80	60-65	75-85
Wind speed (m sec^{-1}.)	2-3	2-3	1-2
Fuel potency (ton ha^{-1})	10-20	15-20	10-15
Moisture content (%)	10-70	30-60	20-60
Flame temperature (°C)	500-600	> 830	700-800

Green house gases emission (CO_2, CO, CH_4 and N_2O)

Most tropical fires are set or spread accidentally or intentionally by humans and are related to several causative agents; some of them limited to subsistence livelihood, others to commercial activities (Qadri 2001). Emissions from burning the cleared vegetation depend on the degree of combustion that is achieved, i.e. the proportion of biomass consumed by fire (Brinkman 2009). If fire is continued to be used for land preparation in peat areas the status of peat become critically endangered (Saharjo 2007). Forest fires release toxic gases like carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), hydrocarbons, aldehydes, particles and polycyclic aromatic hydrocarbons (PAHs) (Ostermann and Brauer 2001). It is known that exposure to these gases can cause acute respiratory infections. In 2000, Southeast Asia contributed 12% of global GHG emissions, amounting to 5,187.2 $MtCO_2$-eq, including emissions from LUCF (ADB 2009)

CO_2 emission

Peat soil, with higher moisture content compared to alang-alang and peat grass, had the highest CO_2 emission (Table 2). This is understandable due to smoldering combustion was dominant. In alang-alang grassland, because the fuel was relatively dry, flaming combustion dominated. Flaming combustion accounts for most of the fuel consumption in grass fires. However, the emissions from smoldering combustion in grass fires also play an important role in tropical dry season tropospheric chemistry (Granier et al. 1996) and in tropical and temperate forests consume a much larger percentage of the fuel by smoldering combustions (Ward et al. 1992). Grassland management has the potential to sequester carbon by 0.11- 1.50 tCO_2 ha^{-1} per year (ADB 2009).

Table 2. CO_2 , CO, CH_4 and N_2O emission (ppm) during burning in alang-alang, peat soil and grass

Parameter	Land type		
	Alang-alang	Peat soil	Peat grass
CO_2	(1494.3±1246.1)b	(21466.7±7731.5)c	(9906.7±5794.0)a
CO	(400.7±136.5)a	(1331.7±409.0)b	(6717.3±4584.8)c
CH_4	(7.1±5.8)a	(475.3±250.4)b	(507.7±149.1)c
N_2O	-	(1201.0±185.8)a	(1828.0±347.8)b

Note: Means are significantly different when standard errors are followed by different letters (p≤0.05)

Peat grass combustion emitted the second largest CO_2 (Table 2). This can be understood because grass that lives in the peat has quite high moisture content (an average of more than 50%) which then slows the combustion processes. These high moisture contents of peat grass required more energy and time to reach the ignition temperature. This situation can be seen clearly through flame temperature of peat grass burning that vary from 700-800°C. Carbon dioxide can account for 99% of the C emissions in efficient burns that is burns consuming most, if not all, of the available fuels, but account for only 50% in low-intensity smoldering fire (Debano et al. 1998).

CO emission

Carbon monoxide emission in peat grass was the highest among the three sites (Table 2). High moisture content of peat grass resulted in incomplete burning and low-intensity fire. Low combustion resulted in high CO emission during combustion compared to alang-alang grassland and peat soil. Field fire experiments show that fires in the peat grass was slow and required much time to reach the ignition temperature of 360°C needed for spreading compared to alang-alang and peat grass. The resulting low-intensity fire, produced CO, which is commonly produced with incomplete combustion of moist fuels. High emissions of CO have been measured on the fire line of relatively low-intensity fire (Sandberg et al. 1975) and the amount of CO emitted by fire is a function of combustion efficiency, increasing as efficiencies drop (Debano et al. 1998). The emission factor (amount of the compound released per amount of fuel consumed) of CO for peat grass (0.636 mol CO/mol CO_2) was the highest compared to peat soil (0.0509 mol CO/mol CO_2) and alang-alang (0.0082 mol CO/mol CO_2). The emission ratio of CO/CO_2 from peat grass was higher than that reported by Ward (1986) and Greenberg et al. (1984), but less than reported by Lacaux et al. (1993).

CH_4 emission

The first step in the combustion of vegetation is the pyrolitic decomposition of plant matter immediately ahead of the flames, this releases a wide array of reduced and partially oxidized organic compound with CH_4 being the most abundant species (Andreae et al. 1996). Peat grass combustion emitted more CH_4 than alang-alang grassland and peat soil. High CH_4 emission resulting from peat grass combustion is believed to be due to the fuel bed characteristics of grass, especially on compaction and pattern (Table 2). Physically the performance of peat grass seems to be the same as alang-alang grassland but then combustion is actually different. The peat grass grows in bunches which are rather thick at the bottom compared to alang-alang grassland. This condition affects the combustion processes. During the early, flaming stage, when the temperature is high and the combustion zone is well oxygenated, the emissions of partial combustion products are low. The proportion of the total combustion process which is made up by each stage is mainly controlled by the physical attributes of the fuel and to a lesser degree by the weather during the fire (Scholes et al. 1996). This emission ratio of CH_4 observed in our study from peat grass (Table 3) was higher than that reported by Andreae (1991) and Akeredolu and Isichei (1991) but less than reported by Lacaux et al. (1993), both from savannas and forests.

Table 3. Emission factors reported for vegetation fires

Emission factor (Original units)	Emission factor (g kg^{-1})	Reference
Carbon monoxide (CO)		
0.055-0.145 g CO_2/g CO_2		Ward (1986)
0.05-0.3 mol CO/mol CO_2		Greenberg et al. (1984)
6.1 mol CO/mol CO_2		Lacaux et al. (1993)
	230 (forest)	Scholes et al. (1996)
	63-73 (savannas)	Scholes et al. (1996)
	59-97 (grasslands)	Scholes et al. (1996)
0.636 mol CO/mol CO_2 (peat grass)		This study
0.0509 mol CO/mol CO_2 (peat soil)		This study
0.0082 mol CO/mol CO_2 (alang-alang)		This study
Methane (CH4)		
0.0062-0.016 mol/mol		Andreae (1991)
0.012 mol/mol		Akreedolu and Isichei (1991)
	1.0-1.8	Ward et al. (1992)
	1.8-4.3	Bonsang et al. (1991)
	4.5	Greenberg et al. (1984)
	9.47 (forest)	Scholes et al. (1996)
	1.8-2.3 (savannas)	Scholes et al. (1996)
	1.7-3.4 (grassland)	Scholes et al. (1996)
0.313±0.89 mol CH_4/mol CO_2	1.3-2 (savannas)	Lacaux et al. (1993)
0.313±0.89 mol CH_4/mol CO_2	6-8 (forests)	Lacaux et al. (1993)
0.0018-0.016 mol/mol		Hao et al. (1990)
0.0354 mol/mol (peat grass)		This study
0.0093 mol/mol (peat soil)		This study
0.000028 mol/mol (alang-lang)		This study
Nitrogen Monoxide plus Dioxide		
0.061-0.417 g N-NOx/g N-fuel		Ward (1990)
0.3-3.5 x 10^{-3} mol NOx/mol CO_2		Lobert et al. (1991)
	16.1 (forest)	Scholes et al. (1996)
	4.4-5.1 (savannas)	Scholes et al. (1996)
	4.2-6.8 (grasslands)	Scholes et al. (1996)
1.01 x 10^{-4} mol/mol(peat grass)		This study
6.10 x 10^{-5} mol/mol(peat soil)		This study

N_2O emission

Peat grass combustion emitted more N_2O than the peat soil (Table 2). Peat grass is an N-rich a fuel compared to alang-alang grassland which is usually used as a poor land indicator. N_2O emission ratio from peat grass was higher than peat soil, but les than reported by Lobert et al. (1991) and Scholes (1996). Production of NO(x) by burning is largely dependent on the N content of the fuel consumed. Both NO and NO_2 are reactive gases that are emitted from combustion (Lobart and Warnatz 1993). NO is a thermally stable product of combustion. Although NO_2 is less stable than NO, its abundance increases in smoldering fire (Clements and McMahon 1980).

CH_3Br, CH_3Cl and CH_3I emission during burning in the alang-alang, peat soil and peat grass

Peat grass produces more CH_3Br, CH_3Cl and CH_3I emission (Table 4) during burning compared to alang-alang grassland and peat soil. The amount of chlorine and bromine released to the atmosphere during a fire depend on chlorine and bromine concentration in the fuel burned, the contribution of the fuel to the aboveground biomass and the percentage of fuel burned (McKenzie et al. 1996) and also depend on fire intensity and combustion efficiency (Reinhard and Ward 1995). CH_3Cl, CH_3Br together with CH_4 play a significant role in stratospheric ozone chemistry (Mano and Andreae 1994). CH_3Br (methyl bromide) releases atomic bromine, which leads to the catalytic chemical destruction of stratospheric ozone, which is very similar to the catalytic destruction of stratospheric ozone by chlorine (Levine 1996) and the discovery that methyl bromide is an important combustion product of biomass burning identified a previously unknown and very important connection between biomass burning and the chemical destruction of stratospheric ozone.

Table 4. CH_3Br, CH_3Cl and CH_3I emission during burning in the alang-alang, peat soil and peat grass

Parameter	Land type		
	Alang-alang	Peat soil	Peat grass
CH_3Br	(543.0±508.1)a	(25.6±3.4)b	(41.1±9.8)c
CH_3Cl	(1420.7±416.1)a	(280.0±83.3)b	(694.7±340.3)c
CH_3I	(38.6±11.2)a	(1.0±0.6)b	(1.5±0.8)c

Note: Means are significantly different when standard errors are followed by different letters (p≤0.05)

Biomass burning releases a large amount of aerosol into the atmosphere, which in turn reduces the solar radiation absorbed at the Earth's surface and it can reduce the rainfall over a large area. For urban and industrial areas, there is evidence that air pollution can suppress rain and snow (Rosenfeld 2000; Givati and Rosenfeld 2004). The aerosol (smoke) entrained in a cloud may modify its development by increasing the number of, and depressing the size of, ice crystals within them (Sherwood 2002; Sherwood et al. 2006; Jiang et al. 2008). This will suppress precipitation in the cloud and also change the electrical properties of the cloud. It is known that the highest measured lightning currents with the largest charge transfers are associated with positive lightning. These positive cloud-to-ground (+CG) lightning strikes, even though a small percentage (10%-12%) of the total, are the most 15 efficient for fire ignition. Some recent examples are given in McGuiney et al. (2004); Wotton and Martell (2005).

CONCLUSIONS

Peat grass, where smoldering combustion was dominant due to the high moisture content, produced more trace gasses (CO, CH_4, N_2O, CH_3Cl, CH_3Br and CH_3I) than alang-alang grassland and peat soil. Dry fuel combustion was dominated by flaming combustion in the alang-alang grassland resulted in lower trace gas production. Fuel characteristics (moisture content, type, pattern and potency) and environmental condition (relative humidity, wind speed and air temperature) determine trace gasses production during burning.

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