ORIGINAL ARTICLE

Smoke Composition of Burning Fire in Dry Deciduous Dipterocarp Forest at Huai Kha Khaeng Wildlife Sanctuary, Uthai Thani Province

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ABSTRACT

Smoke composition of burning fire in dry deciduous dipterocarp forest at Huai Kha Khaeng Wildlife Sanctuary was studied in twelve 30 x 30 m^2 plots with completely randomized design. Smoke composition was investigated in three plots per each month from January to April in 2003 and 2004. The smoke composition was recorded every two minutes in eight cardinal directions during burning. Comparisons of the result differences between the first year and second year were made.

The results revealed that the surface fire intensity was not severe. Smoke composition included CO, NO_2, SO_2 and CO_2. Concentrations of them from the first year burning were 48.87 ppm, 1.86 ppm, 0.46 ppm and 0.12 percent, respectively. Almost all gas concentrations from the first year burning were generally higher than those of the 1995 one hour Ambient Air Standards of Thailand. Those from the second year burning were not significantly different from the first year burning (CO = 28.27 ppm, NO_2=1.61 ppm, SO_2 = 0.21 ppm and CO_2 = 0.08 percent), and these gas concentrations were near the 1995 one hour Ambient Air Standards of Thailand. Almost all of the gas concentrations in the smoke composition from burning were higher than those of the 1995 one hour Ambient Air Standards of Thailand.

Key words: smoke composition, burning fire, dry deciduous dipterocarp forest, Huai Kha Khaeng Wildlife Sanctuary

INTRODUCTION

Forest fires cause the global temperature to rise, which in the long run will have a very negative effect on living organisms. The forest fire may directly reduce the beauty of the scenery, and the spreading of its emitted gas and smoke may be dangerous to people within the country and neighboring countries. So the forest fire is both a national and international environment problems.

Forest fires and biomass burning produce and release particulate matter and gases into the atmosphere. Particulate matter emitted from smoldering combustion causes smoke and degraded air quality. Particulate

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matter can also cause haze, which reduces atmospheric visibility. Gases such as carbon monoxide and carbon dioxide are also produced during the combustion of biomass fuels. Moreover, other gases are released into the atmosphere including nitrogen oxide and methane. However, the composition of the combustion products depends on the fuel types, fuel chemistry and fire behavior (Chandler *et al.*, 1983).

Sandberg and Dost (1990) found that the carbon dioxide emission factor for prescribed fires ranged from 2,200 to 3,500 pounds per ton of fuel consumed (1,098 to 1,747 g kg^{-1}). Particulate matter emission factors for forest fuel types ranged from 4 to 180 pounds per ton (2 to 90 g kg^{-1}), while emission factors for other products of combustion such as carbon monoxide ranged from 70 pounds per ton (35 g kg^{-1}) during flaming combustion to 800 pounds per ton (399 g kg^{-1}) for some smoldering fires. Volatile organic compounds are a diverse class of substances containing hydrogen, carbon, and other elements such as oxygen. They include methane, polynuclear aromatic hydrocarbons, and aldehydes and related substances. Methane and aldehydes are emitted as gases. Emissions for volatile organic compound vary from 4 to 50 pounds per ton (2 to 25 g kg^{-1}) of burned fuel, about half of which is commonly methane (Mahaffey and Miller, 2003).

Carbon monoxide is a product of combustion that is rapidly diluted at a short distance from a fire and therefore poses little or no risk to community health (Sandberg and Dost, 1990). However, carbon monoxide can be presented at high enough levels near a fire to pose a hazard to firefighters, depending upon the concentration, duration, and level of activity of the firefighters at the time of exposure. Carbon monoxide is a chemical asphyxiate that interferes with oxygen transport in blood. Pilots exposed to carbon monoxide have developed headaches, fatigue, decreased concentration and impaired judgment. Data also suggest that long-term exposure to low levels of carbon monoxide produce accelerated arteriosclerosis, increasing the risk of cardiovascular diseases such as heart attack and stroke (USDA Forest Service Southern Region, 1989).

Oxides of sulfur and nitrogen occur in smoke, and because forest fuels contain minute amounts of sulfur and somewhat higher level of nitrogen, it is expected that these criteria pollutants are formed when wildland fuel is burned. Increased levels of oxides of sulfur have never been measured near wildland fires. Some oxides of nitrogen form, but the amount produced by forest burning is not significant enough to be of concern (Sandberg and Dost, 1990).

In addition to haze from burning causing reduction in visibility, particulate matter is the most important category of pollutants from wildland fire, because it reduces visibility and can absorb and transmit harmful gases. Particles vary in size and chemical composition, depending upon fire line intensity and the character of the fuels (Wade, 1986).

During the 1991 Indonesia haze episode, horizontal visibility at many places dropped to below two kilometers on most

of the days with the worst condition (minimum visibility recorded was below one kilometers on the 11th October at most of the observation stations) (Cheang *et al.*, 1991). The low visibility led to closures of airports and cancellations of flights. River visibility in Borneo and marine traffic in the Strait of Malacca were also disrupted (Asian Development Bank, 2001).

Economic loss from the disruptions of traffic was tremendous. A study by Shahwahid and Jamal (1988) estimated that those flight cancellations in the 1997 haze resulted in sales losses of 2.6 million US dollars to the Malaysian Airline System. In Mae Hong Son, Thailand, the most serious problem of forest fire is air communication, when the sky is covered by smoke. Thai Airway had to cancel 731 domestic flights from Bangkok in 1995, which resulted in an estimated loss of 114 million US dollars.

Many haze and atmospheric pollution studies have been conducted by researchers. The short-term effects of smoke-haze from the 1997 Indonesian forest fires found that atmospheric concentrations of particulate matter, SO_2, CO, CH_4 and CO_2, and relative humidity were elevated, and photosynthetically active radiation and ambient temperature were reduced by the smoke-haze. Despite elevated CO_2 levels, photosynthesis in three tree species was reduced by the smoke-haze, both indirectly through reduced Population Attributable Risk (PAR) levels, and directly through elevated aerosol and atmospheric pollutant levels (Davies and Unam, 1999). Ayers *et al.* (1997) investigated the 1994 haze episode in Peraling Java, Kuala Lumpur and showed threefold increases in particle less than 10 μm in diameter (PM_{10}) loading during the peak haze event and also showed that the particle less than 10 μm in diameter (PM_{10}) component consisted of approximately 25 percent inorganic components, 25 percent elemental carbon and 50 percent organic materials.

Artaxo *et al.* (1993) studied aerosol particles from tropical forest and savanna fires in several experiments in the Amazon Basin. During the fire season, aerosol concentrations in the whole area of the Amazon Basin were very high. Far from burning plumes, the mass concentration of inhalable particles exceeded 300 gm^{-3}. Large amounts of fine particles were injected into the atmosphere, where they traveled over long distances. The elements emitted were K, Ca, S, Cl, P, Si, Al, Mg, Fe, Mn, Ti, Zn, Cu, Ni, Pb, V, Cr, Br, Rb and Sr. The emissions of trace elements and heavy metals into the global atmosphere due to biomass burning can be very high. Aircraft measurements showed an average atmospheric aerosol loading of more than 350 μgm^{-3} at 1,000 m altitude.

In addition, this study showed that several essential plant nutrients such as P, S, and N were transported in large amounts in the atmosphere as a result of the biomass burning processes. Most of the aerosol particles was water-soluble and could be active as cloud condensation nuclei (CCN), having the potential to change the cloud formation mechanisms in the Amazon Basin and other regions of the planet.

However, the extent of impacts would depend on the frequency and intensity of

fire, fuel load, type of forest involved, and climatic factors. The controlled application of fire to wildland fuels in either their natural or modified state, under specific environmental conditions which allow the fire to produce the fireline intensity and rate of spread required to attain planned resource management objectives is called prescribed burning and is a very useful silvicultural tool (Goldammer, 1993).

Huai Kha Khaeng Wildlife Sanctuary witnessed one of the most devastating forest fires during the months of February and March in 1998 (Giri and Shresta, 2000). Forest fire occurs from mid December until late April and the peak fire season occurs in March. Fires usually start from the eastern border of Huai Kha Khaeng Wildlife Sanctuary where agricultural activity is extensive in the buffer zone, and spreads to the deciduous forest including mixed deciduous forest, dry deciduous dipterocarp forest and bamboo forest. According to Phonboob (1998), dry bamboo is prone to forest fire ignition. A study by Kaitpraneet (2000) highlighted that these 100 kilometers length buffer zones were adjacent to the agricultural areas of 45 villages.

Although the role of fire is to maintain this forest type's condition, fire is a critical element in shaping the ecology of Huai Kha Khaeng Wildlife Sanctuary because fire occurs annually. WEFCOM final project document suggested that little or no information yet exists on the fire ecology of the Huai Kha Khaeng Wildlife Sanctuary (Ministry of Energy and Environment, 1998). In supporting of ecological monitoring efforts, it is essential that a more focused in-depth study of the key factors, such as fire ecology, should be undertaken. Moreover, there was no study about smoke composition from forest fires in Thailand, this study is designed and planned to determine the smoke composition during burning over various periods in a month time-scale on the dry deciduous dipterocarp forest ecosystem and compare the gas concentrations in the smoke composition form burning fire to the 1995 one hour Ambient Air Standards of Thailand.

MATERIALS AND METHODS

Smoke composition of burning fires was studied at Huai Kha Khaeng Wildlife Santuary, Uthai Thani Province. The study was conducted in the dry deciduous dipterocarp forest at Huai Kha Khaeng Wildlife Sanctuary. Twelve 30 x 30 m^2 plots were laid out in completely randomized design.

The study was done in 2003 and in 2004. Three plots of 30 x 30 m^2 in size were burned in each month from January to April in 2003 and again in 2004. Fire was lit at the center of the plot. Smoke composition data from both years' burning were collected during burning. Gas emission from smoke while fuel was burning was measured randomly at 50 points in the 30 x 30 m^2 sample plots. The smoke compositions and concentrations were analyzed by using CA-CALC-Combustion Analyzer. This tool showed the smoke composition and concentration by digital number. Smoke compositions were compared among studied

months, between the first year burn and the second year burn, and compared to 1995 one hour Ambient Air Standards of Thailand by using a computerized software package.

RESULTS AND DISCUSSION

The fuel loads in pre-burn conditions ranged from 0.60 to 3.87 tons ha^{-1}. The highest total fuel load was found in April. Litter is the main fuel contributing to the forest fire in dry deciduous dipterocarp forest. Fuel moisture contents in this study were relatively high, while fire intensities were low, thus, fuel consumption was relatively low. However, after burning was done, there was a significant loss in load of gross fuel. The mean gross load decreased 58.14 percent in the first year burning, while it decreased 73.40 percent in the second year burning. However, the results indicate that one year (twelve months) after burns, fuel load was roughly 70 percent of its pre-fire state.

The immediate effect of burning is the release of gases and particulate matter into the surrounding environment. The amount of particulate put into the air depends on amount and type of fuel consumed, fuel moisture content, and rate of fire spread as determined by timing and type of firing technique used. Rate of smoke dispersal depends mainly on atmospheric stability and wind speed (USDA, 1989).

Smoke composition and concentrations found in this study by using TSI's CA-CALC combustion analyzer included carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and carbon dioxide (CO_2). The smoke concentrations from the first year burning and the second year burning are shown in Table 1.

Table 1 indicated that mean CO concentration from the first year burning was 48.87 ppm. The highest concentration was 70.35 ppm in January, while the lowest concentration was 37.97 ppm in April. Mean CO concentration in February was slightly higher than that in March but they were not significantly different. However, most of the data were generally higher than that of the 1995 one hour Ambient Air Standards of Thailand. In contrast, the mean CO concentration from the second year burning was 20.84 ppm. The highest concentration was found in March and only the CO concentration from this month was higher than that of the 1995 one hour Ambient Air Standards of Thailand. The results showed significant differences between the first and the second year burning in all burn month, although these differences were too small to be significant in the mean concentrations.

Mean NO_2 concentration from the first year burning was 1.86 ppm. The highest concentration was 3.80 ppm in March, while the lowest concentration was 0.05 ppm in January. Mean NO_2 concentration from the second year burning was 1.61 ppm. The NO_2 concentrations in January and February were significantly different from the concentrations in March and April. However, almost all of the concentrations were generally higher than that of the 1995 one hour Ambient Air Standards of Thailand except the mean concentration in January. The results were shown

Table 1. Concentration (mean) of smoke compositions of the first year burning (2003) and the second year burning (2004) in dry deciduous dipterocarp forest at Huai Kha Khaeng Wildlife Sanctuary

Burn month	Smoke concentration							
	CO (ppm)		NO_2 (ppm)		SO_2 (ppm)		CO_2 (%)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
January	70.35 A[1]a[2]	3.12 Ab	0.05 A	0.00 A	0.60 Aa	0.00 Ab	0.05 A	0.08 AB
February	44.88 Ba	3.08 Ab	2.30 Ba	0.33 Ab	0.66 Aa	0.00 Ab	0.10 Ba	0.07 ABb
March	42.27 Ba	80.70 Bb	3.80 C	3.15 B	0.57 A	0.85 A	0.17 C	0.15 A
April	37.97 Ca	26.19 Ab	1.29 Da	2.97 Bb	0.02 B	0.00 A	0.16 Ca	0.04 Bb
Average	48.87	28.27	1.86	1.61	0.46	0.21	0.12	0.08
Standard[3]	30.00		0.17		0.30		-	

Remark: [1] Means followed by a different letter are significantly different ($p<0.05$) among the months (A, B, C)

[2] Means followed by a different letter are significantly different ($p<0.05$) between the 1st year and the 2nd year burning (a, b)

[3] 1995 one hour Ambient Air Standards of Thailand (Ministry of Science, 1995)

that only the mean concentrations in February and April were significantly different between the first and the second year burnings.

Mean SO_2 concentration from the first year burning was 0.46 ppm. The highest concentration was 0.66 ppm in February, while the lowest concentration was 0.02 ppm in April. Means of SO_2 concentration in January, February and March were not significantly different, but they differed from the means concentration in April. However, almost all of the concentrations were generally higher than that of the 1995 one hour Ambient Air Standards of Thailand except the mean concentration in April. Conversely, mean SO_2 concentration from the second year burning was 0.22 ppm. Almost all of the concentrations were lower than that of the 1995 one hour Ambient Air Standards of Thailand except the mean concentration in March. The mean SO_2 concentrations of the first and the second year burnings were not statistically different.

Mean CO_2 concentration from the first year burning was 0.12 percent. The highest concentration was 0.17 percent in March, while the lowest concentration was 0.05 percent in January. Means of CO_2 concentrations in March and April were not significantly different, but they differed from the means for all other months. Means of CO_2 concentration in January and February were significantly different from the means in other months. Mean CO_2 concentration from the second year burning was 0.08 percent; the highest was 0.15 percent in March and the lowest was 0.04 percent in April. Differences in the means of concentration in February and April between the first year and the second year burning were too small to be significant.

There was no study on the smoke composition from the forest fire in Thailand. The smoke from forest fire was measured by the Pollution Control Department after the uncontrolled forest fires from Indonesia under favorable meteorological condition resulted in rapid air quality deterioration over South-East Asia region. The transboundary transport of smoke caused the haze effects not only in Indonesia, but also all over the Malayan peninsular in 1997. The smoke was spread to the southern Thailand. The air quality in Southern Thailand monitored during 1996-1997 showed that the SO_2 as high as 118 ppb in Phuket during June 1996 (the standard is 300 ppb), NO_2 was high peak of 132.8 ppb (the standard is 170 ppb) and the high level of CO was 45.4 ppm (the standard is 30 ppm). Moreover, the air quality monitored found the maximum of particulate matter (PM_{10}) was 314.1 μg m^{-3} (the standard is 120 μg m^{-3}) and the 4 hours with the highest of 142.8 ppb O_3 (the standard is 100 ppb) (Phonboon, 1998).

CO_2 is one of the most important greenhouse gases and is the one of most concern. Its concentration in the atmosphere has increased greatly over recent decades that were due to human activities. The amount of carbon emitted from a fire depends on the vegetation which was killed, the area burned, the type of forest, and the weather and burning conditions which determined the fuel consumption. Direct carbon release is usually approximated through fuel combustion estimation, whereas post-fire carbon releases incorporate

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decomposition of materials that were created by the fire.

This study assumed that initial carbon released came from burning of aboveground fuel loading on-site only. The calculation was applied from the methodology developed by the Intergovernmental Panel on Climate Change (IPCC) meeting in Sao Paulo in 1990.

The IPCC resolved to do this by creating a network of local scientists in tropical countries and by using a common framework in order to estimate the emissions and uptake of carbon for each country (Puangchit, 1994) to estimate carbon dioxide emission from burning.

The major trace gases released from burning were CH_4, CO, N_2O, and NO_x. Emissions of trace gases were estimated by multiplying the emission ratio of the trace gases by the total carbon released from on-site burning. The results of CO_2 and non-CO_2 trace gas emission from the first year burning and the second year burning were presented in Table 2.

The CO_2 emission was calculated from the fuel load loss, highest total loss fuel load, highest CO_2 emission (April from the first year burning and February from the second year burning). CO_2 emission from both the first and the second year burning in each month's burning were not significantly different as well as mean CO_2 emission from the second year burning which showed no significant differences with the first year burning.

Non-CO_2 trace gas emissions were calculated from CO_2 emission, so non-CO_2 trace gas emission were also highest in the month with highest total fuel load loss. Although non-CO_2 trace gas (CH_4, CO, N_2O, and NO_x) emissions were not significantly different among the burn months, the mean of non-CO_2 trace gas concentration from the first year burning was significantly higher than that from the second year burning ($p<0.05$). This could be explained by the lower fuel load consumption in the second year burning causing the lower smoke concentration than the first year burning. In addition to the different of other uncontrolled factors as the moisture content of fuel and atmosphere, the temperature and time during burnings made the different results.

Compared to the total net emission from the forest, in the 1994, the net carbon emission from forest totaled 16,493 Gg-C or 60,476 Gg-CO_2. While Non-CO_2 trace gases in the same year show the emissions of CH_4, CO, N_2O, and NO_X were estimated at 59.57, 521.21, 0.41 and 14.80 Gg, respectively.

CO_2 is a natural component of the atmosphere with a content of about 0.036 percent. CO_2 is generated within bodies continuously that breathe out CO_2. But in high concentrations it may displace oxygen and cause asphyxia. Very high concentrations of atmospheric CO_2 can produce a state of hypercapnia or an excessive amount of CO_2 in the blood (Nahas *et al.*, 1968 ; Brackett *et al.*, 1969 ; Van Ypersele de Strihou, 1974), which typically results in acidisis, a serious and sometimes fatal condition characterized in humans by headache, nausea and visual disturbances (Poyart and Nahas, 1968; Turino *et al*., 1974). However, these phenomena do not have any impact on human health until the atmosphere's CO_2 concentration reaches

Table 2. CO_2 **and non-**CO_2 **trace gas emissions of the first year burning (2003) and the second year burning (2004) in dry deciduous dipterocarp forest at Huai Kha Khaeng Wildlife Sanctuary**

Burn month	Gases emission (Gg) [1]									
	CO_2		CH_4		CO		N_2O		NO_x	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
January	0.13267	0.10880	0.00948 a[2]	0.00565 b	0.08294 a	0.04944 b	0.000065 a	0.000039 b	0.00236 a	0.00140 b
February	0.09375	0.18135	0.00741	0.00850	0.06486	0.07434	0.000051	0.000058	0.00184	0.00211
March	0.16356	0.16430	0.01095	0.00795	0.09577	0.06957	0.000075	0.000055	0.00272	0.00198
April	0.23172	0.14612	0.01166 a	0.00685 b	0.10203 a	0.05992 b	0.000080 a	0.000047 b	0.00290 a	0.00170 b
Average	0.15543	0.15014	0.00987 a	0.00724 b	0.08640 a	0.06332 b	0.000068 a	0.000050 b	0.00245 a	0.00180 b

Remark: [1] Gg = giga gram (billion or 10^9)

[2] Means followed by a different letter are significantly different ($p<0.05$) between the 1st year and the 2nd year burning (a, b)

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approximately 15,000 ppm (Luft *et al.*, 1974; Schaefer, 1982), which is approximately 40 times greater than its current concentration.

In addition to gases from burning such as CO, NO_2, SO_2, CH_4, hydrocarbon, and various other gases, which can be harmful in high concentrations, the smoke is also made up of particle matter smaller than 10 microns in size (PM_{10}). Department of Environmental Quality Division of Air Quality (2001) showed that these particles penetrate deeper and remain longer in the lungs than other matters. PM_{10} also contains large quantities of organic materials that may have significant long-term health effects. Unfortunately TSI's CA-CALC combustion analyzer could not analyze particle matter concentration.

In this study, the results showed that all of the gas concentrations that were produced by combustion were higher than the standard value. Gases from burning were released, rapidly diluted and returned to the atmosphere in a matter of hours so there is low probability that public health is at risk. Gases can be present at high levels near a fire depending upon the concentration, duration, and level of activity of the firefighters at the time of exposure. Therefore concern is increasing over the risk to firefighters and the general public from exposure to toxins, irritants, and known carcinogens in smoke. Therefore, firefighters who work in smoke environment for a prolonged period without wearing protection may suffer harmful exposure to these gases. The appropriateness and effectiveness of the protection techniques should be further studied.

CONCLUSIONS

The study of the smoke composition from burning in dry deciduous dipterocarp forest at Huai Kha Khaeng Wildlife Sanctuary, Uthai Thani Province was concluded as followings;

Smoke composition by using TSI's CA-CALC combustion analyzer included CO, NO_2, SO_2 and CO_2. Concentrations of CO, NO_2, SO_2 and CO_2 from the first year burning were 48.87 ppm, 1.86 ppm, 0.46 ppm and 0.12 percent, respectively. Almost all gas concentrations from the first year burning were generally higher than the 1995 one hour Ambient Air Standards of Thailand. Those from the second year burning were not significantly different from the first year burning (CO = 28.27 ppm, NO_2=1.61 ppm, SO_2 = 0.21 ppm and CO_2 = 0.08 percent), and these gas concentrations were close to the 1995 one hour Ambient Air Standards of Thailand. The concern is concentrated to the risk of firefighters and the general public from exposure to toxins, irritants, and known carcinogens in smoke.

Carbon release came from burning of aboveground fuel loading, and CO_2 emission calculation in this study was applied from the methodology developed by the IPCC meeting in Sao Paulo in 1990. The highest total fuel load loss in April from the first year burning and February from the second year which burning found the highest CO_2 emission. CO_2 emissions from both the first year and the second year burning in each month were not significantly different. Also mean CO_2 emissions from the

second year burning showed no significant differences with the first year burning.

The non-CO_2 major trace gases, namely; CH_4, CO, N_2O, and NO_x were also released from burning. Emissions of trace gases are estimated by multiplying the emission ratio of the trace gases by the total carbon released from on-site burning. Although non-CO_2 trace gas (CH_4, CO, N_2O, and NO_x) emissions were not significantly different among the month burnings, the means of non-CO_2 trace gas concentrations from the first year burning were significantly higher than that from the second year burning ($p<0.05$). This could be explained by the higher fuel load consumption from the first year burning causing the higher smoke concentration than the second year burning.

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