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Estimation of Carbon Released from Dry Dipterocarp Forest Fires in Thailand

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***Abstract*—**This study focused on the estimation of carbon released to the atmosphere from dry dipterocarp forest (DDF) fires in Thailand. Laboratory experiments were conducted using a cone calorimeter to simulate the DDF fires. The leaf litter collected from DDF in western Thailand was used as biomass fuel. Three different masses of leaf litter were employed, 7g, 10g and 13g, to estimate the carbon released from this type of vegetation fire to the atmosphere. The chemical analysis of the leaf litter showed that the carbon content in the experimental biomass fuel was 46.0±0.1%. From the experiments, it was found that more than 95% of the carbon input was converted to carbon released to the atmosphere, while less than 5% were left in the form of residues, and returned to soil. From the study, the carbon released amounted 440.213±2.243 $g/kg_{dry\ biomass}$, and the carbon retained in the residues was 19.786±2.243 $g/kg_{dry\ biomass}$. The quantity of biomass fuel consumed to produce 1g of carbon released was 2.27±0.01$gkg_{dry\ biomass}$. Using these experimental data of carbon produced by the DDF fires, it was estimated that this type of fires in 2009 contributed to 4.659 tonnes of carbon released to the atmosphere, and 0.229 tonnes of carbon in the residues to be returned to soil in Thailand.

***Keywords*—**Carbon mass balance, carbon released, tropical deciduous forest, biomass burning.

I. Introduction

FOREST fires in dry dipterocarp forest (DDF) occur in Thailand during the dry season, from December to April, when trees shed their leaves, and consequently, the leaf litter can accumulate quickly, and then serve as perfect fuel for burnings to be set by local communities. Fires of tropical deciduous forests, including dry dipterocarp forest and mixed deciduous forest in Thailand are generally man-made. The reasons frequently recorded by forest fire control stations are (1) to facilitate the gathering of non-timber forest product, (2) to ease the access to forest for hunting, and (3) to help land clearing for crop cultivation [1]. The type of fires occurred in DDF is characterized as surface fire, since the fuel is composed of biomass present on the ground surface of the forest, including leaf litter, twig, grass, undergrowth, shrub, climber, and seedling. The leaf litter constitutes the major component of biomass fuel. Studies on fuel consumption indicated that about 95% of biomass fuels in DDF are consumed by surface fires [2].

Regarding impacts of fires on the ecosystem, it was shown that the frequency of fire can drastically modify the structure and composition of aboveground biomass and affect the carbon cycle. Actually, the more frequent is the burning the lower is the growth rate. It was observed that in the annually burned area, the increase of tree diameter and basal area was lower than that of biennially, which was lower than that of triennially burned, with only 0.237cm/year and 0.0007m/year, respectively. Concerning the survival to fire which depends on the base diameter, it was found that the seedlings with base diameter less than 1cm were completely dead after the fire passage [3]. It was revealed that fires directly affect biomass fuel characteristics, as well as underneath soil properties and nutrients dynamics [4]. Indeed, the heat from fires distresses insects on the ground or under the bark wood, and activates the natural regeneration and undergrowth development [3]. Although their adverse effects, it should be noted that fires play an important role in tropical deciduous forest management, because they enable to maintain its plant structure and ecosystem.

On the other hand, emissions from forest fires strongly affect air quality. They include air pollutants and climate forcers such as carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O), fine particulate matter (PM_{10} and $PM_{2.5}$), carbonaceous aerosols composed of black carbon (BC) and organic carbon (OC), etc. While these compounds adversely impact the local air quality and long-term climate change, documentations on qualitative and quantitative characteristics of the emissions from dry dipterocarp forest fires in Thailand are still very scarce or inexistent.

In this study, we investigated the carbon released from dry dipterocarp forest fires, by burning leaf litter corresponding to the major biomass fuel type. After describing the laboratory experiments conducted using cone calorimeter, the analysis of the carbon content in the biomass fuel and burned residues is presented. The amount of carbon released to the atmosphere and able to be sequestered estimated from the carbon mass balance of the combustion reaction was then discussed.

II. Materials and Methods

A. Carbon Mass Balance

The carbon mass balance (CMB) of a chemical reaction is defined as

$$C_{input} = C_{output} \quad (1)$$

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where, C_{input} is the amount of carbon input to the reaction, and C_{output} is the amount of carbon output from the reaction.

In case of forest fires, (1) can be expressed as

$$C_{biomass} = C_{ash} + C_{oxidized\ or\ released} \quad (2)$$

where, $C_{biomass}$ is the amount of carbon in biomass consumed (gC) and C_{ash} is the amount of carbon in ash and charred leaf (gC), $C_{oxidized\ or\ released}$ is the amount of carbon oxidized or released to the atmosphere (gC).

In case of a complete combustion, the carbon released to the atmosphere would be equal to the carbon in the form of carbon dioxide (CO_2). As forest fire is always an incomplete combustion, the carbon released is composed of carbon dioxide (CO_2) representing more than90% of the total, carbon monoxide (CO) corresponding to minor component (i.e. lesser than 5% of the total) [5], [6] and trace carbonaceous compounds including gaseous species such as methane (CH_4), non-methane volatile organic compounds (NMVOCs), etc., and carbon-contained particulate matter, including black carbon (BC) and organic carbon (OC).

B. Fire Experiments with Cone Calorimeter

The used leaf litter was from dry dipterocarp forest at Mae Nam Phachi Wildlife Sanctuary, Ratchaburi, Thailand. Samples were collected from 1m x 1m sub-plots during dry season of 2011-2012, i.e. December 2011 to April 2012. They were carried to the laboratory to oven-dried at 70-80°C for at least 24h or until reaching a constantweight. Three different masses, i.e. 7, 10, and 13g of leaf litter were put in the stainless steel basket of 14cm diameter and 3.6cm height, used as sample holder (Fig. 1), which corresponds to actual biomass fuel density of 4.547 t/ha, 6.496 t/ha, and 8.444t/ha. The basket was perforated, and two diameters of hole were available, i.e. 0.5cm for the left one, and 0.1cm for the right one (Fig. 1), to let the air penetrate in the fuel bed during the combustion. In this study, only the basket perforated with small size hole was used. To burn the biomass fuel, the heater of the cone calorimeter was set at 750°C and 40 kW/m^{2}power. The cone calorimeter was utilized for conducting the fire experiments, because it enables to simulate the open burning processes and to measure and monitor the associate emissions as well as the mass loss and the products of the combustion reaction.

For each experiment, we assured that the biomass fuel was ignited at the applied temperature and power, and it was totally burned, i.e. there is none unburned fraction that would require an adjustment of the carbon mass balance of the simulated combustion reaction. Cases for which the ignition was not obtained were eliminated from data analysis. The ignition time, flame residential time, and mass loss during combustion were monitored and continuously recorded.

C. Carbon Content Analysis

After oven-dried at 70-80°C for at least 24h or until reaching a constant weight, the leaf litter samples were cut using the cutting mill SM 2000 model, Retsch, Germany, and ground with the ball mill PM_{10} model, Retsch, Germany until obtaining a powder with diameter lesser than 100µm. The ground samples were then analyzed for the carbon content by Organic Elemental Analyzer, Flash EA1112 NC-Soil model, Thermo Finnigan, Italy. The same analytical procedure was applied to residues after burning, composed of a mixture of ash and charred leaves.

III. Results and Discussions

A. Characteristics of Residues after Burning

After burning, the residues were composed of ash and a fraction having a shape close to the original leaf structure, as shown in Fig. 3. The carbon content of the residues, mass of fuel used, and mass loss by the combustion are reported in Table I. For all the experiments, the leaf litter was totally consumed. The mass of residues formed from the combustion to the mass of fuel used ratio for 7g, 10g and 13g, were 11.14%±2.57%, 11.30%±1.30%, and 9.15%±0.62%, respectively. This showed that the mass fraction of the residues resulted from the combustion was nearly constant whether the mass of fuel applied, while the carbon content varied with the mass of fuel. This result reflects the condition of oxygenation of the burning. Actually, the height of the basket being fixed, the change in fuel mass led to an increase of fuel bed compaction, and so to a decrease of oxygenation, i.e. to a more incomplete combustion. In addition, the higher is the carbon content in the residues; the lower is the amount of carbon released to the atmosphere.

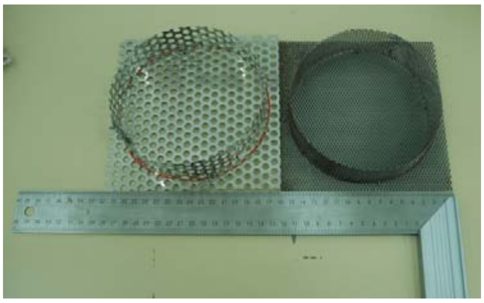

Fig. 1 Stainless steel basket used as sample holder

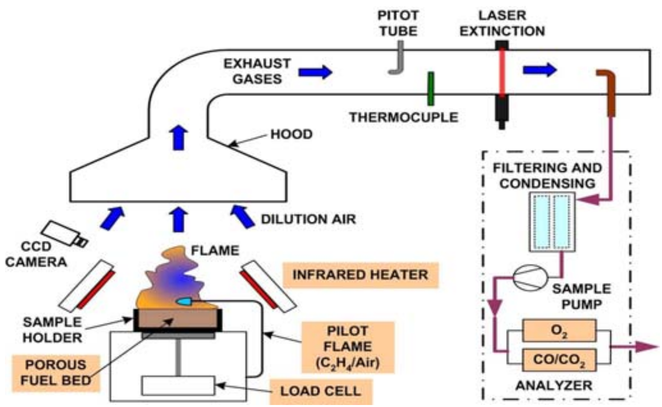

Fig. 2 Cone calorimeter diagram

(a) (b)

Fig. 3 Leaf litter before (a) and after burning (b)

TABLE I
MASS LOSS AND LEFT AFTER BURNING, %CARBON CONTENT AND MASS OF CARBON IN THE RESIDUES AFTER BURNED

Sample	Mass (g)		% Carbon content	Mass (g) of carbon in the residues
	Mass loss	Mass left after burning		
7g leaf litter	6.22±0.18	0.78±0.18	15.5±1.4	0.120±0.002
10g leaf litter	8.87±0.14	1.13±0.13	19.1±1.9	0.216±0.002
13g leaf litter	11.10±0.08	1.19±0.08	22.4±1.8	0.266±0.001

B. Estimation of Carbon Released

The obtained results indicated that the carbon content in the leaf litter was 46.0±0.1%, equivalent to 460 gC/kg$_{\text{dry biomass}}$. In the residues after burning of 7g, 10g and 13g leaf litter contained 15.5%±1.4%, 19.1%±1.9% and 22.4%±1.8% of carbon, respectively. Normalized to a unit of biomass fuel, in mass of carbon in the residues to mass of fuel used (g/kg dry biomass), the carbon content in residues after burning were 17.271, 21.583 and 20.504g/kg$_{\text{dry biomass}}$ for the case of 7g, 10g and 13g of leaf litter experiment, respectively. It should be noted that the carbon in the residues would be progressively returned to soil as the residues are left on the ground surface after fires.

The resulted carbon released for each experiment is reported in Table II. It could be noticed that the carbon released per unit of fuel is quite constant and amounts 440.213±2.243 g/kg$_{\text{dry biomass}}$. On the other hand, the carbon in residues after burned (a mixture of ash and charred leaf) represents the amount of carbon to be returned to the soil. It should be noted that the amount of carbon released obtained in this study may be overestimated, since it is resulted from cone calorimeter experiments for which the combustion efficiency (CE) was assured to be 100%, while the actual CE of DDF fires in Thailand is generally around 90-99%, with values close to 99% in the case if most of the biomass fuel is composed of leaf litter only. For the same reason, the amount of carbon content in residues may be underestimated.

Based on the results presented in Table II, it was found that each gram of carbon released resulted from 2.27±0.01g leaf litter consumed, which is higher comparatively to the result obtained by Nelson [7].

C. Carbon Released from DDF Fires in Thailand

The statistical data of area burned by DDF fires in Thailand in 2009 were used to investigate the amount of carbon released to the atmosphere. To this end, we applied the average biomass fuel density of 6496.120 kg/ha, which is the average density used for the cone calorimeter experiments.

TABLE II
CARBON RELEASED AND CARBON IN RESIDUES AFTER BURNING

Residue	Carbon content (g/kg $_{\text{dry biomass}}$)	
	Carbon released	Carbon in residues after burning
7g leaf litter	442.728	17.271
10g leaf litter	438.417	21.583
13g leaf litter	439.495	20.504

TABLE III
CARBON EMISSION FROM DDF FOREST FIRES IN THAILAND IN YEAR 2009

Province	Area burned (ha)	Carbon produced by DDF fires (tonnes C)	
		Carbon released	Carbon to soil
Chiangmai	908.16	2.586	0.127
Lampoon	282.08	0.803	0.040
Sukhothai	51.84	0.148	0.007
Tak	76.00	0.216	0.011
Karlasin	94.24	0.268	0.013
Khon-kaen	123.04	0.350	0.017
Mahasarakarm	10.72	0.031	0.002
Roy-ed	23.36	0.067	0.003
Loei	6.72	0.019	0.001
Ratchaburi	15.20	0.043	0.002
Petchaburi	44.48	0.127	0.006

The national statistics of forest fires in 2009 indicated that the total area burned was 1635.84 ha. This contributed to produce 4.659tonnes of carbon released to the atmosphere, and 0.229tonnes of carbon in the residues to be returned to soil. The obtained results by province are reported in Table III. It could be observed that Chiangmai represents the province where the amount of carbon released was the highest, followed by Lampoon, Khon-kaen and Karlasin. Also, it was found that more than 50% of total carbon released was from Chiangmai.

IV. CONCLUSION

The experiments using a cone calorimeter enabled to simulate open burning conditions occurred during forest fires in DDF in Thailand. The results from simulated open burning of DDF leaf litter showed that the amount of carbon released to the atmosphere from DDF fires is 440.213±2.243 g/kg$_{\text{dry biomass}}$, while 19.786±2.243 g/kg$_{\text{dry biomass}}$ of carbon contained in the residues would return to soil. Using the cone calorimeter experimental data, it was found that each gram of carbon released is resulted from the combustion of 2.27±0.01g leaf litter.

Based on these experimental data, it was estimated that the amount of carbon released by DDF fires in Thailand in 2009 was4.659tonnes, and about 0.229tonnes of carbon would be returned to soil. Also, it was shown that Chiangmai represented in 2009 the province where more than 50% of total carbon released were emitted, followed Lampoon, Konkaen, and Karlasin province, respectively.

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