Emission Factors for CO_2, CO and Main Hydrocarbon Gases, and Biomass Consumption in an Amazonian Forest Clearing Fire

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Introduction

- Biomass burning is the second largest source of trace gases and the largest source of primary fine carbonaceous particles in the global troposphere.
- According to Ito and Penner, around 2,290 Tg C/year are released into the atmosphere by biomass burning (2004).
- Mieville et al. estimate that the average total annual emissions of carbon dioxide as a result of biomass burning is 2,714 Tg C/year over the 1997 to 2005 period (2010).

Introduction

- These values can be compared to around 8,180 Tg C/year by fossil fuel combustion, cement production, and gas flaring (Backer et al., IPCC 2007).
- CO_2 released by biomass combustion is equivalent to about 12% of the CO_2 emitted by fossil fuel use (Backer et al., IPCC 2007).
- The average deforestation rate of the Amazon region was 15,815 $km^2\ yr^{-1}$ during the 2000 to 2011 period. (6,961 $km^2\ yr^{-1}$ → 2009-2011).
- Though there have been several scientific studies in this area in the past two decades, global and regional emissions of some of the compounds still need to be investigated.

Objectives

- Quantify biomass before and after fire in a 4-ha area located in the western Amazon region, near the city of Cruzeiro do Sul, Acre state, Brazil.

- Determine, at ground level, the emission factor of the main gases generated during the burn.

- Compare these results with those obtained in an experiment conducted in the arc of deforestation, near the city of Alta Floresta, state of Mato Grosso, Brazil.

Methodology

1 - Aboveground biomass

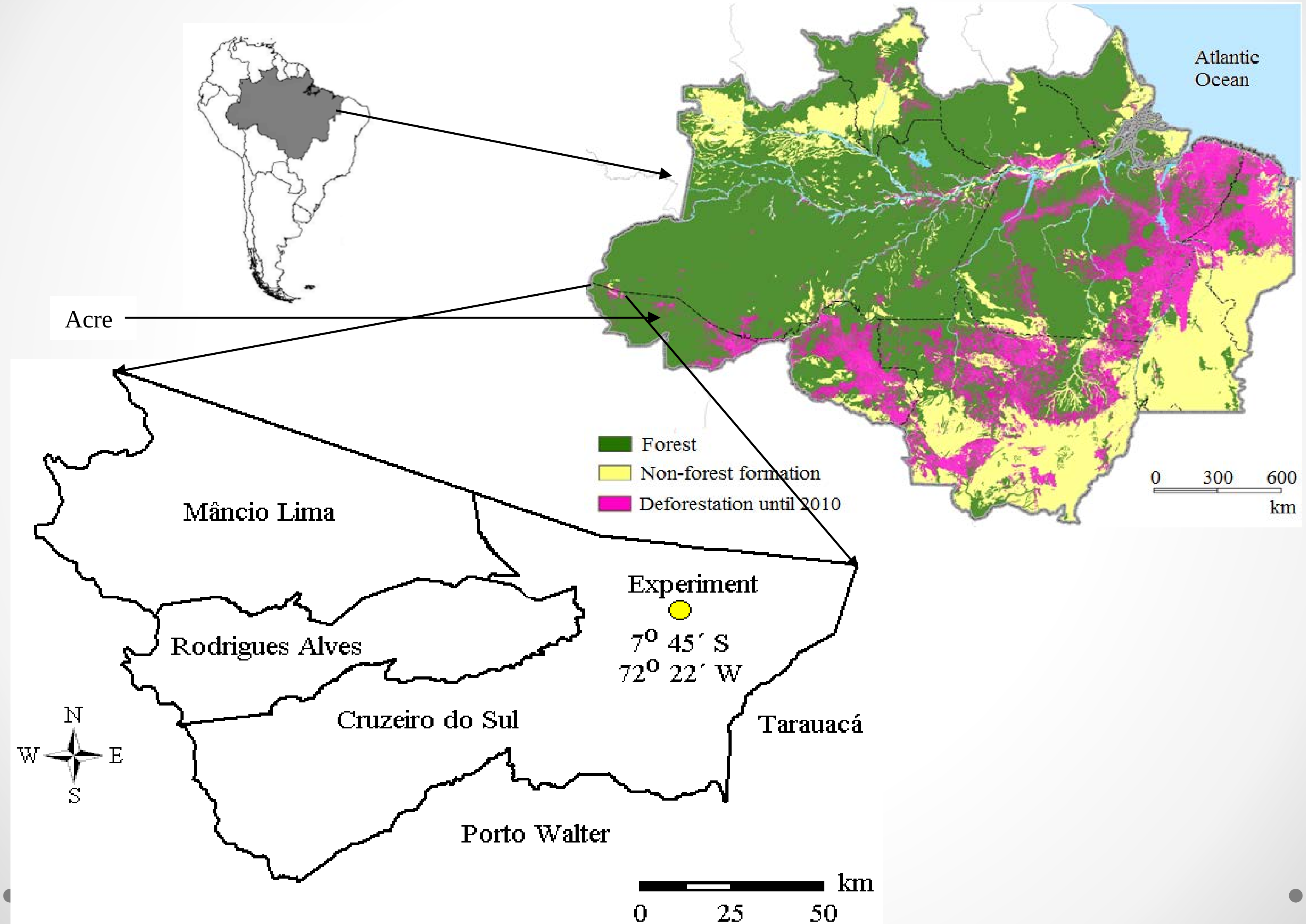
- Test site
- Forest inventory

2 - Biomass consumption

3 - Gas sampling system

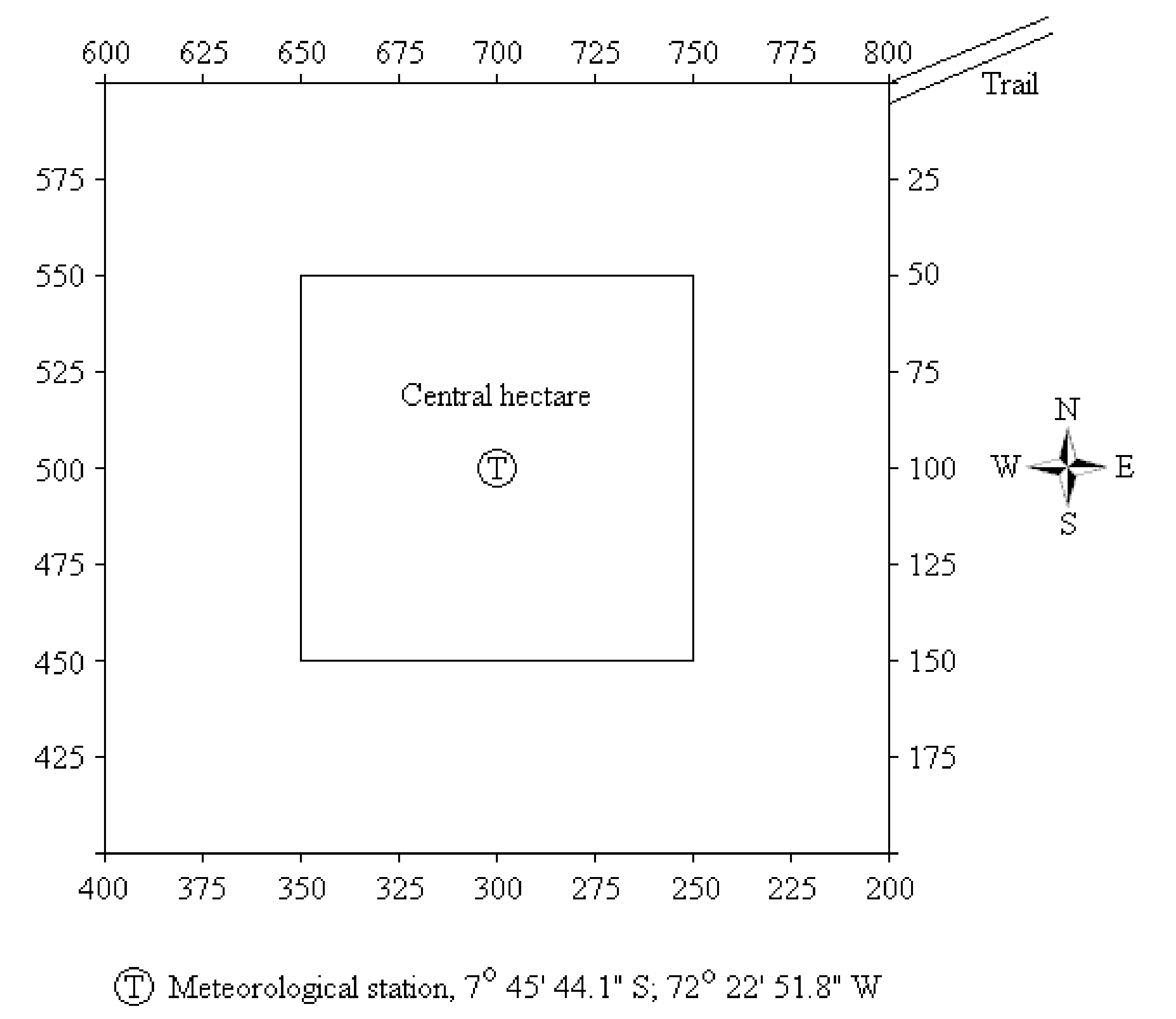
4 - Analytical methods

The Amazon region and location of the test site near the city of Cruzeiro do Sul, Acre, Brazil.



Aboveground biomass

Location of the two areas.



Forest inventory

- Before cutting the vegetation, the forest was inventoried in the central hectare.
- Each specimen had its main characteristics measured (diameter at breast height (DBH), trunk height, and canopy height).
- The allometric equation used to estimate the biomass with DBH > 10 cm was proposed by Santos (1996):

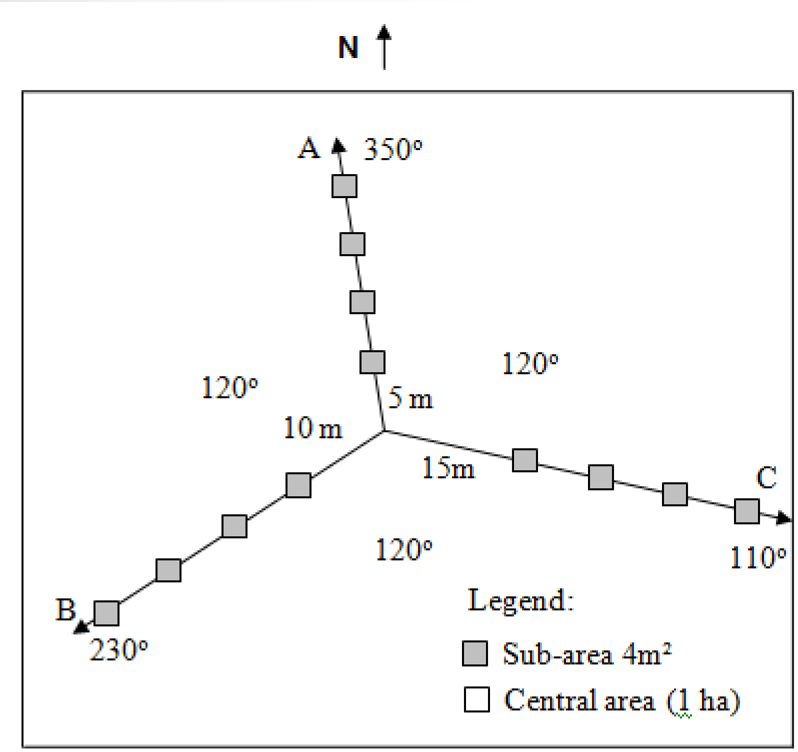
$$FW = \sum \exp\left[3.323 + 2.546 \ln(DBH)\right]$$

- In which FW is the fresh weight (10^3 kg).
- DBH is inserted in meters (m).
- Individuals with DBH < 10 cm and litter were inventoried in 2x2 m^2 areas.

Forest inventory (Cruzeiro do Sul).

Biomass consumption

- The forest was cleared in the beginning of the dry season in June.
- Biomass consumption of small material (DBH < 10 cm) was estimated by weighing the biomass before and after burning, in twelve 2x2 m^2 sub areas.
- Direction A was randomly selected. Small material is composed of leaves, small bushes and branches, litter, and vines. The sub areas were bounded with wires for identification after the fire.



Characterization of biomass before the fire (small material) (Cruzeiro do Sul).

Biomass consumption

- Logs and larger branches (DBH > 10 cm) were considered as medium and large material. Their consumption was estimated based on the procedure by Sandberg and Ottmar (1983).

- 81 logs were selected and identified before the fire and catalogued in a GPS.

- Consumption is calculated by determining the cross section area burned by the fire, and considering the log as formed by two trunks of cone and two cylinders.

Characterization of biomass before the fire (large material) (Alta Floresta).

Gas sampling system

- A 13 m tower with a set of probes, filters, and a manifold with 4 electrovalves was used to collect combustion gases.

- From this manifold, a 100 m insulated PFA tube was installed to transport the gases to the collection system within the forest. The electrical wires were run inside the insulation.

Gas sampling system

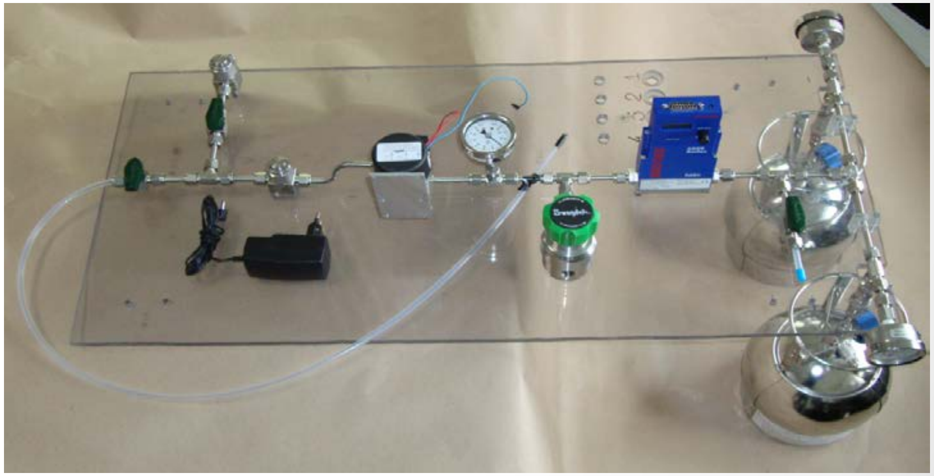
- The collection system was made up of a filter, back pressure valve, flow controller, vacuum and pressurization pump and quick connection for the canisters used to store samples in different combustion phases.

- This system allowed constant sampling in every phase at a certain flow (400 mL/min) and pressure (1.5 atm), regulated at the same time by the flow controller and the back pressure valve.

- The whole collection system was fed by a generator.

Gas sampling system

Shelter box installed in the top of the tower.



Gas sampling system mounted on an acrylic table.

Installation of system for field sampling.

Setting up instrumentation in tower (Cruzeiro do Sul).

Analytical methods

- A PerkinElmer Auto System gas chromatograph was employed for analyzing CO_2, CO, CH_4, and C_2–C_3 aliphatic compounds in canisters.

- Haye Sep D 12 ft column; Helium carrier gas; H_2 flow at the FID detector of 45 ml/min; air flow at the FID detector of 450 ml/min; furnace kept at 45 ºC for 25 min, heated to 120 ºC in 3 min, and kept at a final temperature of 120 ºC for 25 min.

- Flame Ionizing Detector (FID) equipped with a methanizer.

Analytical methods

- To quantify the gases contained in the samples, a calibration curve was constructed for each species.

- Analyses of three standards certified by Air Liquide with known concentrations were carried out.

Area of 200x200 m², felled in June and burned in September 2010 (Cruzeiro do Sul).


Flaming phase.

Smoldering phase

After burning

Results and Discussion

Aboveground biomass - Forest inventory:

- 582 individuals in the central hectare, and the total fresh biomass for DBH > 10 cm was 583 ton ha^{-1}.
- Fresh weight for individuals with DBH < 10 cm and litter was 105 ton ha^{-1}.
- Total fresh biomass was 688 ton ha^{-1}.
- Neto et al. (2009) estimated 528 ton ha^{-1} and Carvalho et al. (2001) estimated 496 ton ha^{-1} in the region of Alta Floresta, state of Mato Grosso; Carvalho et al. (1998) estimated 685 ton ha^{-1} in the region of Manaus, state of Amazonas.
- Forest in Western Acre is as heavy as the one in Central Amazonas, while the one Northern Mato Grosso is 25% lighter.

Results and Discussion

Biomass consumption:

- Biomass consumption was 22.5% for larger trunks.
- Biomass consumption was 89.2% for fine trunks.
- Considering the total consumption of dry biomass, we have an average consumption of 36.1%.
- Overall biomass consumption is near the 40% determined by Carvalho et al (2001) in a series of burns conducted in the same farm for test areas of the same size (4 ha).

Results and Discussion

- **Gas emissions:**

Table 1. $PM_{2.5}$, CO_2, CO and CH_4 total concentrations and CO_2, CO and CH_4 net concentrations

Phase [a]	$PM_{2.5}$ (mg m^{-3})	Total concentrations (ppmv)			Net concentrations (ppmv)[b]		
		CO	CH_4	CO_2	CO	CH_4	CO_2
B	0.00	5.1	1.79	382			
I	6.09	9.4	1.82	405	4.3	0.03	23
F	21.45	130	11.25	2546	125	9.46	2164
In	1.50	237	27.67	2085	232	25.88	1703
S	1.50	130	16.65	1135	125	14.46	753
S	1.00	137	17.93	1095	132	16.14	713
S	0.40	86	11.09	824	81	9.3	442
S	0.40	22.7	3.02	451	17.6	1.23	69

[a] B: background; I: initial, F: flame, In: intermediate; S: smoldering.
[b] Net concentrations

Results and Discussion

- **Gas emissions:**

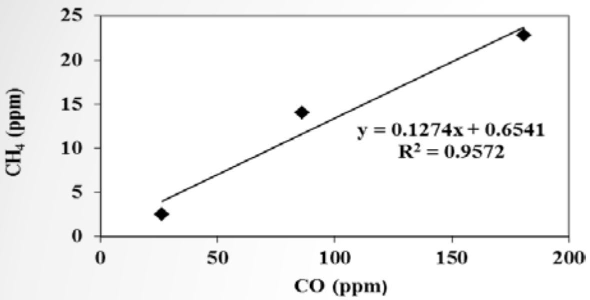
Table 2. Net concentrations for C_2 and C_3 hydrocarbons (ppmv).

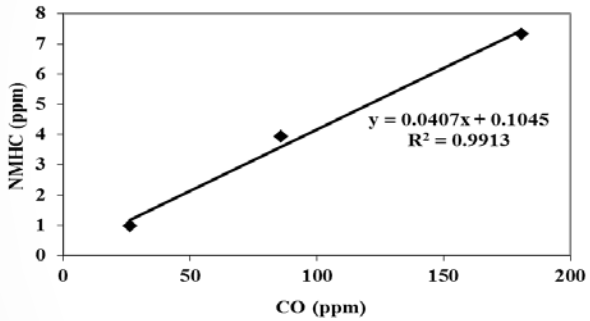
Phase [a]	$C_2H_4 + C_2H_2$	C_2H_6	C_3H_6	C_3H_4	C_3H_8	NMHC [b]
B	0.0	0.0	0.0	0.0	0.0	0,0
I	0.0	0.0	0.0	0.0	0.0	0.0
F	1.15	0.57	0.28	0.12	0.48	2,60
In	2.66	1.50	0.78	0.36	0.70	6.00
S	0.97	0.86	0.38	0.14	0.27	2.62
S	0.70	0.93	0.39	0.20	0.60	2,82
S	0.67	0.58	0.14	0.11	0.49	1.99
S	0.15	0.15	0.00	0.00	0.12	0.42

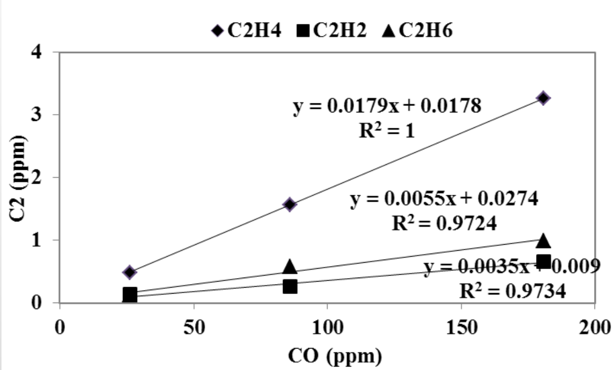
[a] B: background; I: initial, F: flame, In: intermediate; S: smoldering.
[b] Total hydrocarbons other than methane.

Results and Discussion

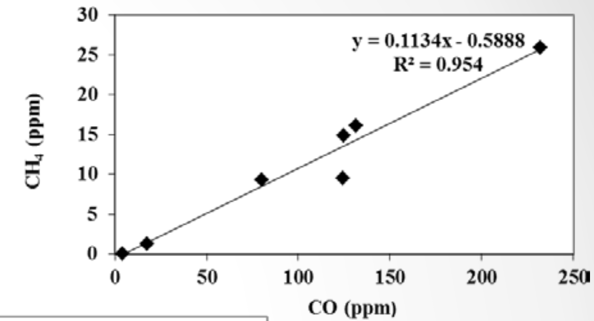
Alta Floresta (2004)

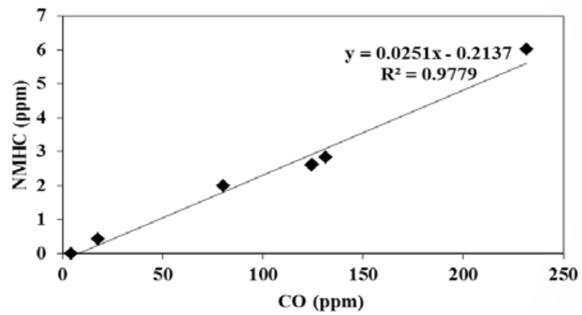






Cruzeiro do Sul (2010)





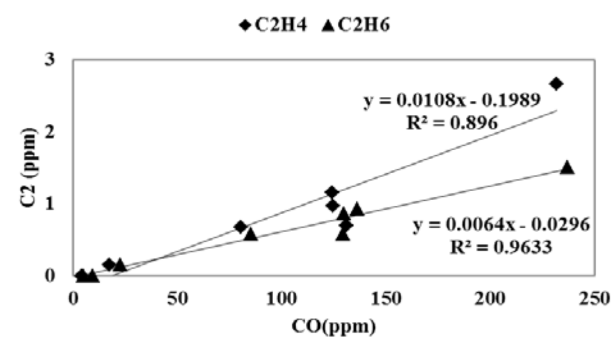


Figure 9. Correlation between CH_4, NMHC, and CO concentrations obtained by chromatographic analysis of product gases collected in canisters from Alta Floresta (Neto et al., 2009) and Cruzeiro do Sul (this work).

Results and Discussion

- **<u>Gas emissions:</u>**

Example of the calculation of the mass of carbon associated with CO_2:

$$\mathrm{C\text{-}CO_2} = \frac{[CO_2]\ x\ M_{CO_2}\ x\ 10^3\ mg\ x\ 12\ g\ C}{V\,CO_2\ x\ 10^{-3}\ x\ m^3\ x\ 44\ g\ CO_2} = 1058.89\ \frac{mg\,C}{m^3}$$

In which:

$[CO_2]$ denotes concentration of CO_2 in ppmv ($2546/10^6$).

VCO_2 is 24.5 L for 1 mole of CO_2 at 25 ºC and 1 atm.

44 is the molecular mass of CO_2 expressed in g.

Results and Discussion

- **Gas emissions:**

Table 3. Emitted carbon associated with each of the analyzed gases.

Canister	Phase[a]	Total C emitted (mg m^{-3})					
		C-CO_2	C-CO	C-CH_4	C-NMHC	C-$PM_{2,5}$	C-total
1	I	11.27	2.10	0.02	0.00	3.65	17.04
2	F	1059	60.96	4.64	2.98	12.87	1140
3	In	834.2	113.5	12.68	6.80	0.90	968.1
4	S	368.8	61.15	7.28	2.94	0.90	441.1
5	S	349.5	64.31	7.91	3.35	0.60	413.8
6	S	216.4	39.35	4.56	2.31	0.24	255.7
7	S	33.91	8.59	0.60	0.47	0.24	42.50

[a] I: initial, F: flame, In: intermediate; S: smoldering.

Results and Discussion

- **Gas emissions:**

CMB method (carbon mass-balance):

$$EF\ CO_2 = \frac{C_1\ x\ 44\ x\ 10^3}{12\ x\ 2\ x\ C} = 1702\ \frac{g\,CO_2}{Kg}$$

In which:

C_1 is the mass of carbon emitted as CO_2 (1059 mg m^{-3}).

C is the total mass of carbon (1140.33 mg m^{-3}).

2 g of the biomass are consumed for each gram of carbon emitted.

Results and Discussion

- **Gas and particle emissions:**

Table 4. Emission factors (g kg^{-1}).

Canister	Phase	EF[a] CO_2	EF CO	EF CH_4	EF NMHC	EF $PM_{2.5}$
1	I	1213	143.8	0.6	0.00	-
2	F	1702	62.4	2.7	1.60	5.64
-	F[b]	1690	62.7	3.4	2.56	7.45
3	In	1580	136.8	8.7	4.29	0.46
-	In[b]	1625	101.2	7.3	4.72	4.21
4	S	1533	161.7	11.0	4.08	1.02
-	S[b]	1540	140.6	13.1	7.49	3.85
5	S	1548	181.3	12.7	4.95	0.72
6	S	1551	179.5	11.9	5.53	0.47
7	S	1463	235.8	9.5	6.76	2.82

[a] values in grams of gas per kg of dry biomass burn.
[b] values obtained in Alta Floresta (Neto *et al.*, 2009)

Results and Discussion

- **Gas emissions:**

- CE – combustion efficiency
- MCE – modified combustion efficiency

$$\mathrm{CE} = \frac{g\,CO_2}{1820}$$

$$\mathrm{MCE} = \frac{CO_2}{CO_2 + CO}$$

Results and Discussion

- **Gas emissions:**

Table 5. Combustion efficiencies

Canister	Phase	CE[a]	MCE[b]	CE[a1]	MCE[b1]
1	I	0.661	0.843	-	-
2	F	0.928	0.946	0.922	0.945
3	In	0.861	0.880	0.886	0.911
4	S	0.836	0.858	0.840	0.874
5	S	0.844	0.845	-	-
6	S	0.846	0.846	-	-
7	S	0.798	0.798	-	-
8	S	0.661	0.843	-	-

[a] CE – Combustion efficiency; [a1] (Alta Floresta, Neto et al., 2009).
[b] MCE – Modified combustion efficiency; [b1](Alta Floresta, Neto et al., 2009).

Results and Discussion

- **Gas emissions:**

Table 6. Average emission factors (g kg^{-1} and kg ha^{-1})

Average emission factors (g kg^{-1})[a]				
CO_2	CO	CH_4	NMHC	$PM_{2.5}$
1513 [a1]	157.3	8.17	3.89	1.86
1599 [a2]	111.3	9.2	5.6	4.8

Average emission factors (kg ha^{-1})[b]				
CO_2	CO	CH_4	NMHC	$PM_{2.5}$
232,115[c]	24,141	1,254	596	285
321,400[d]	33,427	1,736	825	395

[a] values in grams of gas per kg of dry biomass burn.
[a1] (this work); [a2] (Alta Floresta, Neto et al. (2009).
[b] values in kg of gas per ha of burned forest.
[c] values for overall biomass consumption of 36.1%.
[d] values extrapolated to overall biomass consumption of 50%.

Conclusion

- Fresh weight for individuals with DBH ≥ 10 cm was 583 t ha^{-1}. Fresh weight for individuals with DBH<10 cm and litter was 105 t ha^{-1}. The aboveground biomass of the test site was 688 t ha^{-1}.

- The forest inventory showed that the forest in Western Acre was as heavy as the one in Central Amazon, while the one in Northern Mato Grosso is 25% lighter.

- The overall biomass consumption for the test was 36.1%, which is near the value of 40% determined by Carvalho et al.(2001) in a series of burns conducted on the same farm for test areas of the same size (4 ha).

Conclusion

- The emission factors for CO_2, CO, CH_4, C_2–C_3 hydrocarbons, and $PM_{2.5}$, in g kg^{-1} of burned dry biomass, were within the range of other emission factors reported in the literature.

- Using 50% as a worst case scenario for the average biomass consumption for areas larger than 4 ha, 1 ha burned releases about 321,400 kg of CO_2, 33,427 kg of CO, 1,736 kg of CH_4, 825 kg of NMHC and 395 kg of $PM_{2.5}$ into the atmosphere.

Conclusion

- Transforming this emission into CO_2 equivalent and extrapolating for the average rate of annual deforestation of 15,815 km^2 yr^{-1} for the period from 2000 to 2011 (INPE, 2012), the CO_2 equivalent emission rate of 567 Mt year^{-1} for the Amazonian forest represents 1.13% of the global GHG emissions as reported by Barker et al. (IPCC, 2007).

- Results presented in this paper should not be regarded as definitive values. They were obtained in this particular experiment.

Acknowledgments

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Thank you!

Obrigado!