Twenty years of research on forest clearing fires in Amazonia

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Abstract
This paper presents a compilation of the main results obtained by this research group in twenty years of field research on forest clearing fires in the Brazilian Amazon region. Experiments were conducted in Manaus (state of Amazonas) (2 experiments), Tomé-Açu (state of Pará) (1 experiment), and Alta Floresta (state of Mato Grosso) (8 experiments). The research congregated 6 Brazilian and 2 American research institutions. Results on the following main themes of the research are presented:
- Biomass consumption and emission rates of CO_2 under fire;
- Emission factors of combustion gases produced in the burns;
- Log smoldering;
- Under-story fire propagation;
- Charcoal formation;
- Changes of composition of the water percolated through the soil;
- Mercury emissions by fires.
The paper also discusses the newly approved thematic project that will support research for the following 4 years. Experiments will be conducted in Cruzeiro do Sul and Rio Branco (state of Acre) and again in Alta Floresta.

Keywords: biomass consumption, CO_2 emission rates, gas concentrations, log smoldering, under-story fires.

1. Introduction

Biomass burning is one of the most important sources of atmospheric pollution in the planet (Crutzen and Andreae, 1990; Crutzen et al., 1979). This has an important role in the balance of several chemical species in the atmosphere. Estimates indicate that 3 to 5 Pg

(10^{15} g) of carbon are burned annually as biomass (Reinhardt and Ward, 1995; Crutzen and Andreae, 1990; Seiler and Crutzen, 1980), which makes this figure of the same order of magnitude of that relative to carbon burned as fossil fuel.

Biomass is burned for heating, cooking and to prepare the soil in agriculture management. Controlled vegetation burning and accidental forest fires consume millions of hectares every year. In Brazil, 1.7 million hectares of primary forests are burned per year (Andreae and Merlet, 2001).

Clearing and biomass burning are part of the land conversion process that follows the colonization of the Amazon region. Every year, the land preparation process for farming in the Amazon begins in the dry season, during June and July, when the felling starts. At the beginning of the dry season, farmers cut small trees whose diameter at breast height (DBH) is ≤ 5 cm (breast height is ~1.3 m); these are left to cure. These small trees act as fuel to sustain the fire to burn the larger trees. The next step, generally 1 month later, is to complete felling of all trees and vegetation in the area. After 2 months of exposure to sunlight drying the vegetation is sufficiently dry to sustain fire. This is the peak period of emission of gases in the region.

This review article summarizes the results obtained in a large research program that studies biomass fire consumption and forest fire environmental impacts conducted in the Brazilian Amazon region. The following main research topics were investigated in the past 20 years: a) biomass consumption and emission rates of CO_2 under fire (Carvalho et al., 2001, 1998, 1995; Araújo et al., 1999a, 1999b), b) concentrations of combustion gases produced in the burns (Soares Neto et al., 2009; Christian et al., 2007), c) log smoldering (Rabelo et al, 2004; Carvalho et al., 2002), d) under-story fire propagation (Carvalho et al., 2010), e) charcoal formation (Carvalho et al., 2006), f) changes of composition of the water percolated through the soil (Forti et al., 2008), and g) mercury emissions by fires (Michelazzo et al., 2010).

2. Biomass Consumption and Emission Rates of CO_2

The field experiments were carried out in the Caiabi farm (09^o 58' S and 56^o 21' W), near the town of Alta Floresta, state of Mato Grosso, Brazil. Alta Floresta, shown in the map of Figure 1, is located in the Amazonian arc of deforestation, which is the geometric configuration of the advancing frontier of civilization towards the Brazilian rainforest, from South to North, as observed in satellite images.

The tests were performed in five square plots of 1 ha each, designated A, B, C, D, and E, as shown in Figure 2. The following are the main characteristics of each plot: A, was located in the interface with a pasture, with three sides facing directly the forest; it was cut and burned in 1997. B, was located approximately 400 m inside the forest, with four sides directly bordering the forest; it was cut and burned in 1997. C, was located inside a deforested 9-hectare area, which was cut and burned in 1998. D, was located inside a deforested 4-hectare area, which was cut in 1998 and burned in 1999. E, was located inside a deforested 4-hectare area, which was cut and burned in 1999.

Figure 3 presents the consumption as a function of the total deforested and burned area. This curve indicates the tendency to a maximum value of the order of 50% for burns occurring in the same year that the biomass is cut, which is the usual burning procedure in the Amazon region. Using the average carbon content of dry biomass (48%) and the average moisture content of fresh biomass (42%, in terms of mass of moisture per total biomass) determined by Carvalho et al. (1995), and considering the determined biomass of the test site, 496 Mg ha^{-1}, the amount of carbon on the ground before the burning is calculated as 138 Mg ha^{-1}. Assuming that the biomass which remains unburned on the ground keeps the same average of 48% carbon, which is supported by the fact that the unburned material consists mainly of large logs, and considering the value of 50% for the consumption, then the amount of carbon released to the atmosphere as gases during the burn is calculated as 69 Mg ha^{-1}.

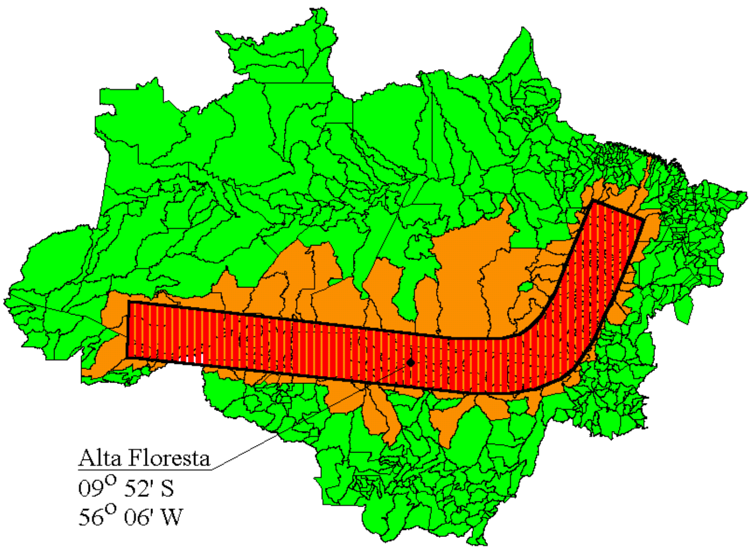

Figure 1 – The Amazonian deforestation arc and the location of Alta Floresta (Source: http//www2.ibama.gov.br/proarco/apresentacao.htm).

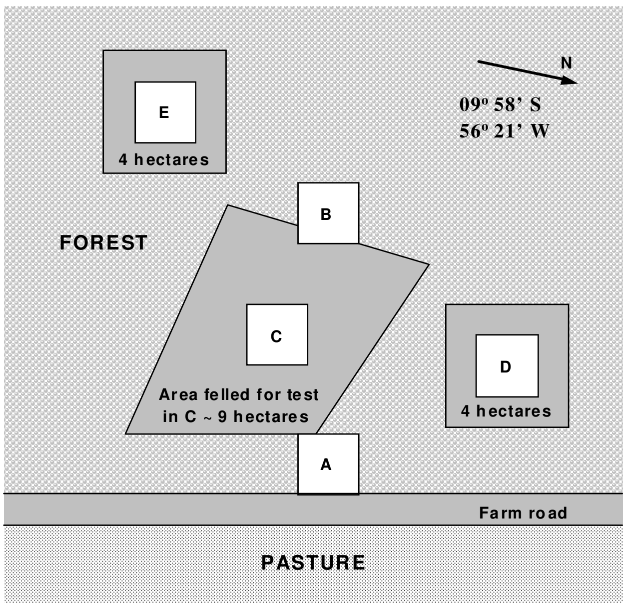

Figure 2 – Location of the 100 x 100 m test plots on Caiabi farm. A and B were felled and burned in 1997, C was felled and burned in 1998, D was felled in 1998 and burned in 1999, and E was felled and burned in 1999 (Source: Carvalho et al., 2001).

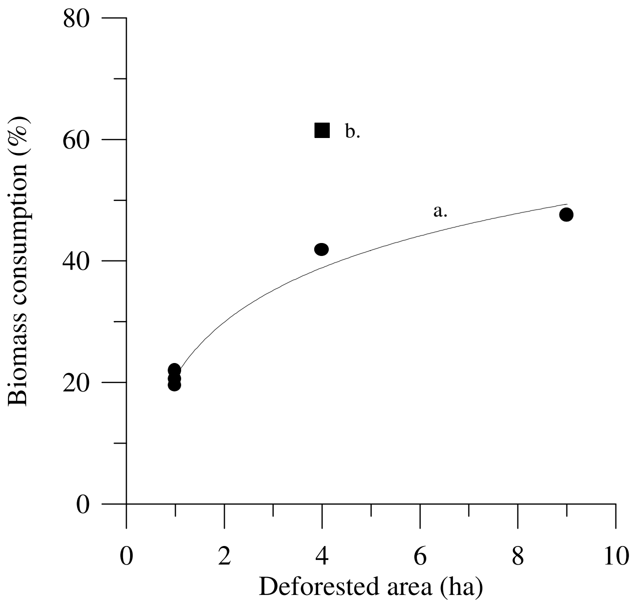

Figure 3 – Biomass consumption in the central 1-ha plot as a funtion of the total deforested and burned area. The circles represent plots that were burned 3 months after they were cut; the square represents the plot that was burned 15 months after it was cut (Source: Carvalho et al., 2001).

The amounts of CO_2 and CO released to the atmosphere by the burning process are estimated by assuming that, in practice, these gases account for 95 - 99% of the carbon released from the fuel (Ward and Hardy, 1991) and that ~ 90% of the CO_2/CO mixture is CO_2 on a volumetric basis (Crutzen and Andreae, 1990). The latter means that in the combustion reaction each Mg of C produces 3.30 Mg of CO_2 and 0.23 Mg of CO.

Taking 97% as the average of Ward and Hardy's (1991) values and 90% CO_2 in the CO_2/CO mixture, the release rates of CO_2 and CO in the experiment were estimated to be 228 Mg ha^{-1} and 15.9 Mg ha^{-1}, respectively.

3. Emission Factors of Combustion Gases Produced in the Burns

The field experiment of this research was also conducted in the Caiabi farm, in Alta Floresta, in 2004. The vegetation in a 200x200 m^2 area was felled during June and burned three months later, in September, 05. The central hectare of the area was divided into 100 squares of 10x10 m^2 each. Six 10x10 m^2 plots were randomly selected. A forest inventory was performed in the central area of 1 hectare prior to the felling of the vegetation. The number of individuals was 552 per hectare, for those with diameter at breast height (DBH) equal to and higher than 10 cm. Individuals with DBH < 10 cm and litter were inventoried in the diagonally opposed 2x2 m^2 areas. Gas samples during the several phases of the burn were obtained with a fire atmosphere sampling system (FASS) that was installed in the center of the area.

Table 1 presents a comparison of the emission data obtained in this investigation with others reported in the literature. Carbon dioxide is the major gas produced during the burning and its emission factor in g per kg of burned material does not vary significantly because it is mostly a function of the biomass carbon content. On the other hand, the formation of other compounds depends more strongly on other parameters, such as type of burning (flaming, intermediate, or smoldering) and vegetation moisture content. Carbon monoxide, methane and non-methane hydrocarbons are produced with larger emission factors during the smoldering phase.

The main results of the experiment can be summarized as follows:

- Fresh weight for individuals with DBH ≥ 10 cm was 410 $t.ha^{-1}$. Fresh weight for individuals with DBH < 10 cm and litter was 118 $t.ha^{-1}$. The aboveground biomass of the test site was 528 $t.ha^{-1}$. The amount of aboveground carbon before the burning was estimated as 147 $t.ha^{-1}$, which within the range determined for the Amazon rainforest, 151 ± 39 $t.ha^{-1}$ (Fearnside et al., 1993).
- The overall biomass consumption for the test was 23.9%, a value lower than 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). The lower biomass consumption occurred because of the rainfall in the 15 days prior to the test.
- Even with the lower biomass consumption, the emission factors for CO_2, CO, CH_4, C2-C3 hydrocarbons, and PM2.5, in $g.kg^{-1}$ of burned biomass, were within the range of other emission factors reported in the literature.
- Using 50% as the estimate for the average biomass consumption for areas larger than 4 ha, the methane emission factor is estimated as 1.412 $t.ha^{-1}$. With the average deforestation rate for the period 2001 – 2006, 20,810 $km^2.year^{-1}$, the methane emission from rainforest burning is 2.94 $Mt.year^{-1}$, which is 27.5% of the value calculated for cattle enteric digestion in Brazil.

The emission factor for CO_2 equivalent to the emitted CH_4 from rainforest burning is 193.2 $g.kg^{-1}$, which is 12.0% of the original 1608 $g.kg^{-1}$ for CO_2 only.

4. Log Smoldering

The characteristics of log smoldering after an Amazonian deforestation fire were investigated. The experiment was carried out in 2001, also in the Caiabi farm, as part of a set of tests that have been performed in the same area since 1997. A 200x200 m^2 test area was slashed in the beginning of June and burned on August 20. The area contained 507 logs with diameter at breast height (DBH) higher than 10 cm, per hectare. In the day following the main burn 59 logs were found to remain smoldering, a number that corresponds to 2.9 % of the total in the area. We chose 11 of the 59 logs to have their smoldering process monitored. Their diameter, moisture content and CHN dry biomass composition after the plot burn and before smoldering were determined. Other parameters such as temperature distribution while smoldering, porosity, density and mass volatilized during thermogravimetric test were also determined. Average smoldering speeds were in the range from 0.8 to 1.5 $cm.h^{-1}$ for logs that smoldered without transition to the flaming regime. The average speed increased to 2.1 $cm.h^{-1}$ for those logs that oscillated between smoldering and flaming. The speeds were lower overnight as compared to values determined during daytime for the same log. Higher log moisture contents were found to produce decreased speeds. Micro-porous biomass was not observed in the set of the 11 selected logs. Smoldering was observed to occur at substantial intensity in crossing of logs, with no longitudinal propagation.

Table 1 – Comparison of data. *Secondary forest. Source: Soares Neto et al., 2009.

CO_2 (g/kg)	CO (g/kg)	CH_4 (g/kg)	NMHC (g/kg)	PM2.5 (g/kg)	Type of Measurement	Reference
1690	63	3.4	2.6	7.5	Ground, flaming	Soares Neto et al. (2009), canisters
1625	101	7.3	4.7	4.2	Ground, intermediate	Soares Neto et al. (2009), canisters
1540	141	13.1	7.5	3.9	Ground, smoldering	Soares Neto et al. (2009), canisters
1741	59	-	-	-	Ground, flaming	Soares Neto et al. (2009), real time
1631	129	-	-	-	Ground, intermediate	Soares Neto et al. (2009), real time
1548	181	-	-	-	Ground, smoldering	Soares Neto et al. (2009), real time
1674	70	5.3	4.3	-	Airborne, flaming	Ferek et al. (1998)
1524	140	8.3	10.4	-	Airborne, smoldering	Ferek et al. (1998)
1649	86	5.1	3.5	9.5	Airborne, average	Babbit et al. (1996)
1671	85	5.0	2.7	3.5	Ground, flaming	Babbit et al. (1996)
1562	140	9.8	4.4	4.2	Ground, intermediate	Babbit et al. (1996)
1515	168	11.8	4.9	4.2	Ground, smoldering	Babbit et al. (1996)
1666	98	4.9	-	-	Airborne, average	Kaufman et al. (1992)
1741	47	2.5	-	5	Airborne, average	Kaufman et al. (1992)
1586	121	7.2	-	16	Airborne, average	Kaufman et al. (1992)
1612	112	7.1	-	6.8	Ground, flaming	Ward et al. (1992)
1551	142	9.0	-	8.9	Ground, smoldering	Ward et al. (1992)
1531	152	10.8	-	6.8	Ground, smoldering	Ward et al. (1992)
1692	73	4.3	-	10.0	Ground, flaming	Ward et al. (1992)*
1652	91	4.8	-	9.2	Ground, smoldering	Ward et al. (1992)*
1637	94	4.9	-	10.4	Ground, flaming	Ward et al. (1992)*
1625	107	5.2	-	7.1	Ground, smoldering	Ward et al. (1992)*

The smoldering front propagation speed was calculated for different periods from August 21 to 23. Equal intervals of time between measurements were not possible. Moving on the burn site at night was a risky task mainly because of the lack of appropriate light. The displacement of the smoldering front as function of time is presented in Figure 4 for nine of the eleven selected logs. Logs 3 and 7 did not smolder in the form of a propagating front. Log 1 oscillated between flaming and smoldering and its resulting average propagation speed was very high as compared to the others'. This log was extremely fibrous and it was inclined in relation to the ground. These may be the reasons for the high observed speed.

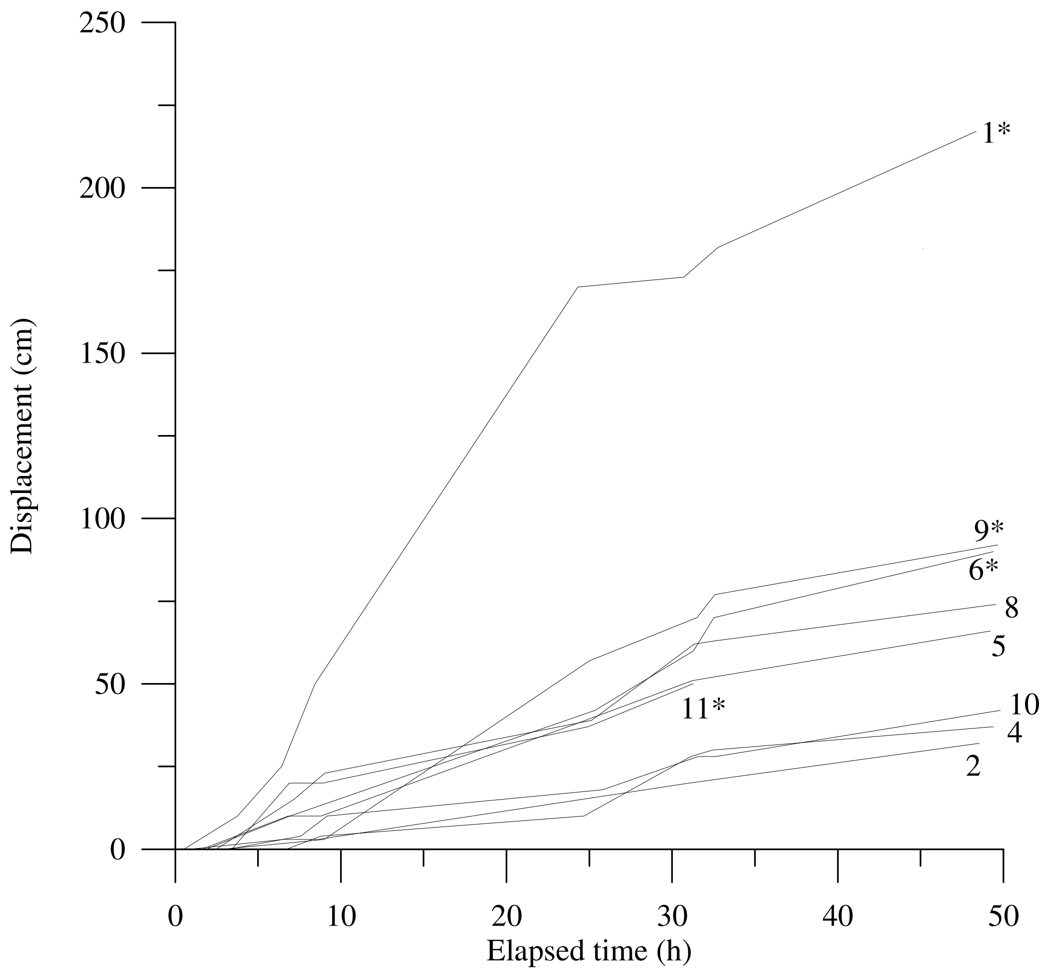

Figure 4 – Variation of smoldering front displacement as function of elapsed time for the selected logs (*: oscillated between flaming and smoldering; 0 –10, daytime; 10 – 22, night; 22 – 34, daytime; 34 – 46, night; 46 – 50, daytime) (Source: Rabelo et al., 2004).

We assorted the remaining eight logs in three groups: those that oscillated between flaming and smoldering (6 and 9), those with low moisture contents (5 and 8), and those with high moisture contents (2, 4 and 10). Log 11 was not considered in this separation between groups because it stopped smoldering during the second day. The moisture contents for logs 5 and 8 were 12.9 and 18.2 %, respectively, and for logs 2, 4 and 10 they were 26.6, 31.2 and 35.9 %, respectively.

Figure 5 presents a linear fit for the displacement of the smoldering front as function of time for each of the three categories. The ‘r’ parameters were 0.975, 0.964, and 0.953, for the top, intermediate, and bottom lines, respectively. The resulting average propagation speeds were: 2.1 $cm.h^{-1}$ for logs 6 and 9; 1.5 $cm.h^{-1}$ for logs 5 and 8; and 0.8 $cm.h^{-1}$ for logs 2, 4 and 10. We recognize that the amount of data available for this analysis does not entitle us to reach conclusions about a quantitative relation between smoldering speed and moisture content, even because speed does not depend solely on moisture content, but the obtained values are indicative of the role of moisture content. A relatively dry log with a length on the order of 10 m may smolder for a month or more if atmospheric conditions remain appropriate. The results reported here are in good agreement to those obtained in the 1999 burn, when the average smoldering speed varied from 0.6 to 2.4 $cm.h^{-1}$ (Carvalho et al. 2002).

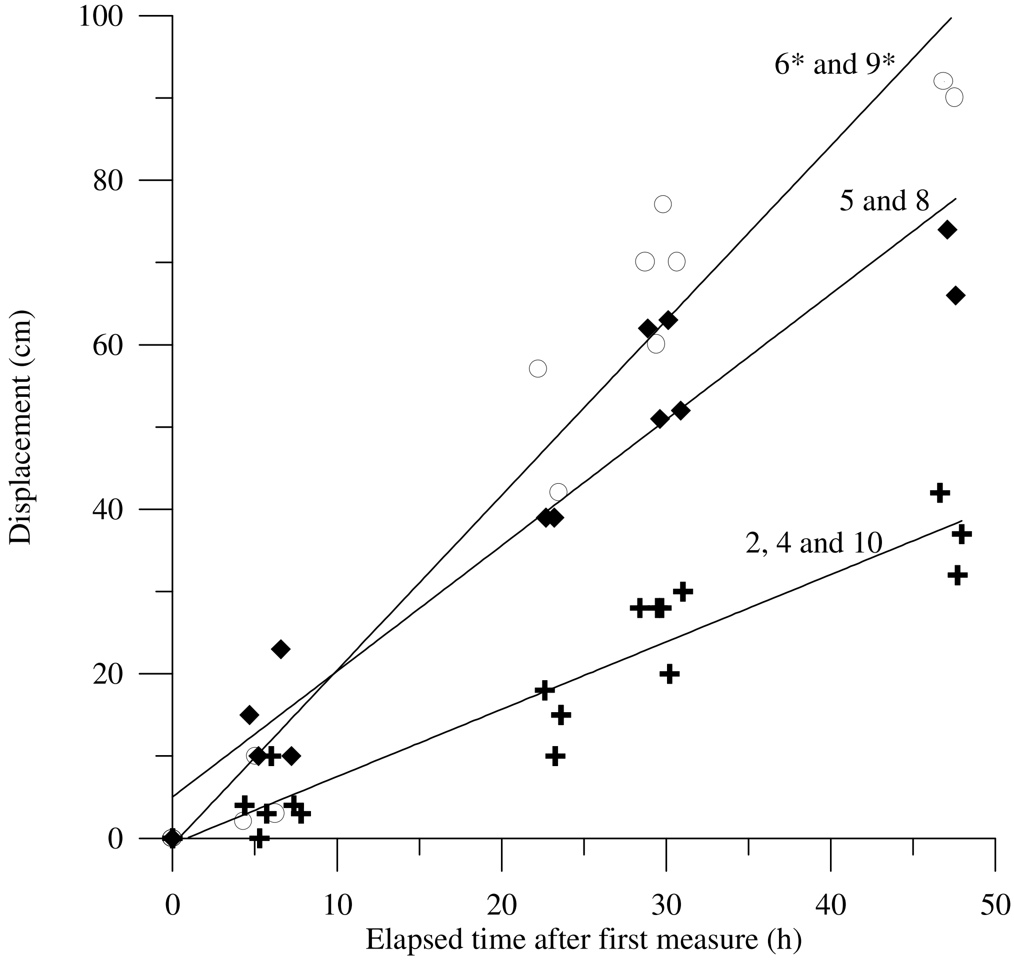

Figure 5 – Variation of smoldering front displacement as function of elapsed time for three groups of selected logs (Source: Rabelo et al., 2004).

Low moisture content was not indicative for occurrence of transition from smoldering and flaming. Logs 6 and 11 oscillated between smoldering and flaming and they possessed two of the highest moisture contents of the 11 logs.

5. Under-story Fire Propagation

Fire characteristics in tropical ecosystems have been scarcely documented quantitatively in the literature. This paper describes an under-story fire propagating across the edges of a biomass burn of a cleared primary forest. The experiment was also carried out in 2001 at the Caiabi farm. The vegetation of a 200×200 m^2 forested area was clearcut during the first week of June and burned in late August. The under-story fire that escaped from the main burn was monitored across the four sides of the land clearing area. The average flame front speed varied between 0.14 and 0.35 m min^{-1}. The flames of the propagating front had maximum heights of approximately 30 cm. Flame depth was on the order of 10 to 15 cm. The mortality of trees was investigated in 2003 in four 20x50 m^2 areas adjacent to the burned 200×200 m^2 forest-clearing site. A total of 210 trees were counted in the four areas. Sixty two of them, 29.5 %, were found dead as a consequence of the under-story fire that had occurred two years before. This fire-caused mortality is an evidence of the synergistic effect between slash burning, tree mortality, and future fire vulnerability on the forest-land clearing interfaces.

The litter constitution (2.38 kg m^{-2}) was basically (> 95%) dead leaves with very little degree of decomposition. The height of the layer was less than 10 cm everywhere. The vegetation in a 200×200 m^2 plot was felled during the first week of June and burned on August 20, 2001. This was a new forest clearing and it was located at approximately 500 m from a farm road and a pasture, and at 50 m from another 200×200 m^2 plot which was deforested and burned in 1999, as shown in Figure 6.

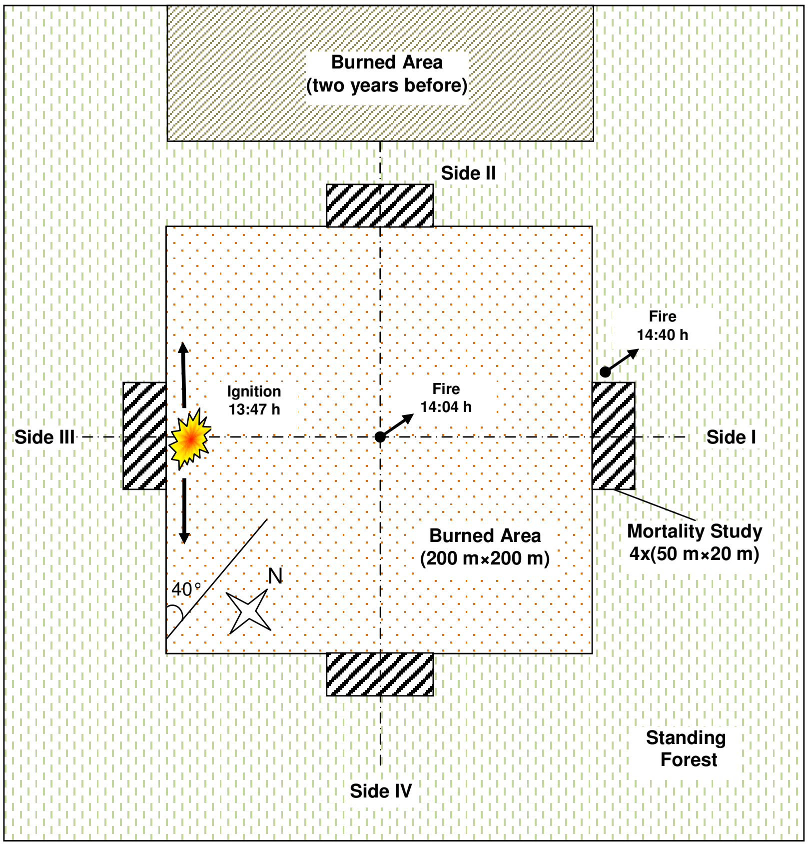

Figure 6 – Test plot of this investigation (Source: Carvalho et al., 2010).

For speed propagation measurements, two methods were employed. The first based on flagging some standing trees with colored tapes and visual observation was employed to set the time the flame front took to travel between two specific trees, whose distance between them was know. This type of measurement suggests average propagation velocities because of the long distances traversed by the flame fronts. We also measured propagation rates with calibrated wooden stakes, meaning smaller length and shorter time scales, which we considered as instantaneous velocities or local flame spread. The stakes were placed perpendicularly to the observed flame front and the rate of spread was measured by dividing the stake length by the time the flame front needed to travel along its length. Although the stakes disturb the flame exactly where they were positioned, no further disturbance was observed in about 15 cm away from each side along the stake. The calculated velocities, by such means, were considered a good approximation of the process. Measurements were taken in the central area of each side, around those set for mortality studies.

Attempts were also taken to measure dynamically flame shape, height and depth by means of visual observation. A metric ruler was positioned close to the flame in the vertical direction to predict heights and through the flame for depth estimations.

The mortality of trees was estimated two years after the fire, in September 2003, by counting dead and live standing individuals in four 20×50 m^2 rectangular areas adjacent to each edge of the burned 200×200 m site. All dead trees found inside these rectangles were tagged, in the pre-burn inventory phase, as to be disregarded in the mortality estimates.

We measured the average litter moisture content in several points along perpendicular transects on the four sides of the area. The objective was to investigate the effect of litter moisture content on fire propagation. The samples were collected within two hours before the burn. Three litter samples were used for each average. The litter moisture was determined at center of the land clearing, on the interface between the land clearing and the standing forest, and at distances of 15, 30 and 45 m from the clearing into the forest.

Results obtained from direct measurements with calibrated stakes, flagging and measuring tapes are presented in Table 2 along with tree mortality and litter local moisture content for sides I, II, III and IV. In the land clearing centre, the litter moisture content was 3.8 %. We expected changes in these values because these data were collected within two hours before the burning. Lower moisture content observed along the sides was due to gaps in the forest canopy. Since wind was absent and most of the terrain was flat, the fire spread determined should be strongly related to fuel bed properties, for short distance propagation, and the presence of obstacles (small standing trees), for long distance travelling.

Table 2 – Measured litter moisture contents, average flame velocities and tree mortality for sides I, II, III and IV (Source: Carvalho et al., 2010).

Location	Parameter									
	Humidity (%)				Flame Speed ($m.min^{-1}$)/Method: Stake (S) and Tape (T)					Mortality
	edge	15 m	30 m	45 m						
Side I	8.6	13.8	11.7	17.3	0.16/S	0.22/S	0.22/S	0.33/S	0.35/S	19.6%
Side II	13.6	13.5	14.7	14.5	0.14/T	0.23/T	0.20/T	extinction	extinction	56.1%
Side III	7.2	12.4	15.4	11.2	0.08/T	0.17/T	0.25/T	0.21/T	0.14/T	22.9%
Side IV	11.3	33.5	11.2	31.8	0.19/S	0.27/S	0.22/S	0.24/S	extinction	25.3%

From Table 2, we observe average flame rate of spread varies from 0.16 to 0.35 m min^{-1} for sides I and II where stakes were used. For comparison, Cochrane et al. (1999) reported a rate of spread of 0.25 m min^{-1} by direct observations of fires at scattered locations within a 150 km^2 area south of Tailândia, state of Pará, Brazil. For sides III and IV measuring tapes were use to infer the rate of propagation for long distances and the velocities varied from 0.14 to 0.24 m min^{-1}. The averages were, 0.26, 0.16, 0.21, and 0.23 m.min-1, for sides I, II, III and IV, respectively.

6. Charcoal Formation

Carbon sequestration through charcoal formation in Amazonian forest clearing fires was quantified in two field experiments. The experiments were conducted in 2004 and 2005, also in the Caiabi farm. The average carbon content of dry biomass was 48% and the estimated average moisture content of fresh biomass was 42% on wet weight basis. A forest inventory was performed in the central area of 1 hectare prior to the felling of the vegetation. The numbers of plant species with a diameter at breast height (DBH) of 10 cm or larger were 552 per hectare for the area of 2004 and 572 for 2005. The total fresh biomass and the amount of carbon on the ground before burning were estimated as 528 t ha^{-1} and 147 t ha^{-1} for the area of 2004 and 437 t ha^{-1} and 122 t ha^{-1} for 2005, respectively. An average of 1.39% of carbon from the biomass was converted to charcoal. Considering that most of the fallen vegetation is burned for clearing the amount of carbon converted to charcoal by forest clearing is estimated as 4.1 Mt $year^{-1}$. This figure was obtained considering the average of 1.39% for biomass carbon converted to charcoal, the average carbon stock of 151 t ha^{-1} for the Amazon forest, and the average deforestation rate of the legal Amazon region of 19,368 km^2 yr^{-1} during the period 2000 to 2007.

On the following days after the burns, the residual charcoal on the ground was collected with shovels and by hand, and stored in plastic bags. Weighing was performed with scales, with a precision of 1 g. The width of the charcoal layer around the felled logs was measured with bark gages. By determining, in laboratory, the moisture content and the density charcoal, the amount of dry material was estimated for the charcoal on the ground and around the logs.

Table 2 presents summary results regarding the charcoal formed during the experiments. The results were obtained considering charcoal average moisture content of 6.02% (determined from 8 samples, in terms of mass of moisture per mass of sample) and charcoal average density of 0.255 $g.cm^{-3}$ (determined from 12 samples, dry basis).

The average charcoal mass for both tests was 2.49 t ha^{-1}. The aboveground fresh biomass was 483 t ha^{-1}. For average biomass moisture content of 42%, for average biomass carbon content of 48%, and considering that charcoal contains 75% of carbon (Fearnside et al., 1999), 1.39% of carbon was left as charcoal.

The mass of charcoal formed in each of the areas was divided by the volume of logs before the fire (V_L) and by the volume of burned biomass (V_B). Equations were found for these parameters and the corresponding volume, and they are presented in Figures 7 and 8.

Table 3 – Summary of charcoal results, for 2004 and 2005 (Source: Carvalho et al., 2006).

2004	Mass of charcoal on the ground, dry (kg).	Mass or charcoal around logs, dry (kg)
Plot 1	2.97	34.94
Plot 2	2.80	15.61
Plot 3	4.30	19.66
Plot 4	0.61	10.07
Plot 5	3.44	37.74
Plot 6	1.00	23.21
Total for 6 plots	15.12	141.22
Total 1 ha	252	2354
Total 2004 (kg)	2606	
2005	Mass of charcoal on the ground, dry (kg).	Mass or charcoal around logs, dry (kg)
Plot 1	8.65	18.03
Plot 2	2.26	12.16
Plot 3	2.44	23.24
Plot 4	2.26	52.39
Plot 5	6.20	1.62
Plot 6	3.95	10.24
Plot 7	14.38	7.85
Total for 7 plots	40.13	125.62
Total 1 ha	573	1793
Total 2005 (kg)	2366	

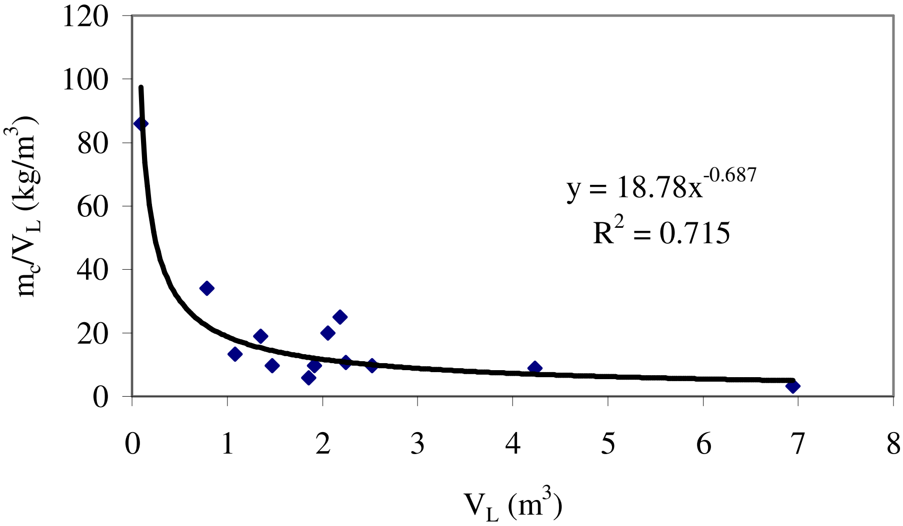

Figure 7 – Variation of the ratio mass of charcoal/volume of unburned logs as function of the volume of unburned logs for each of the selected plots (Source: Carvalho et al., 2006).

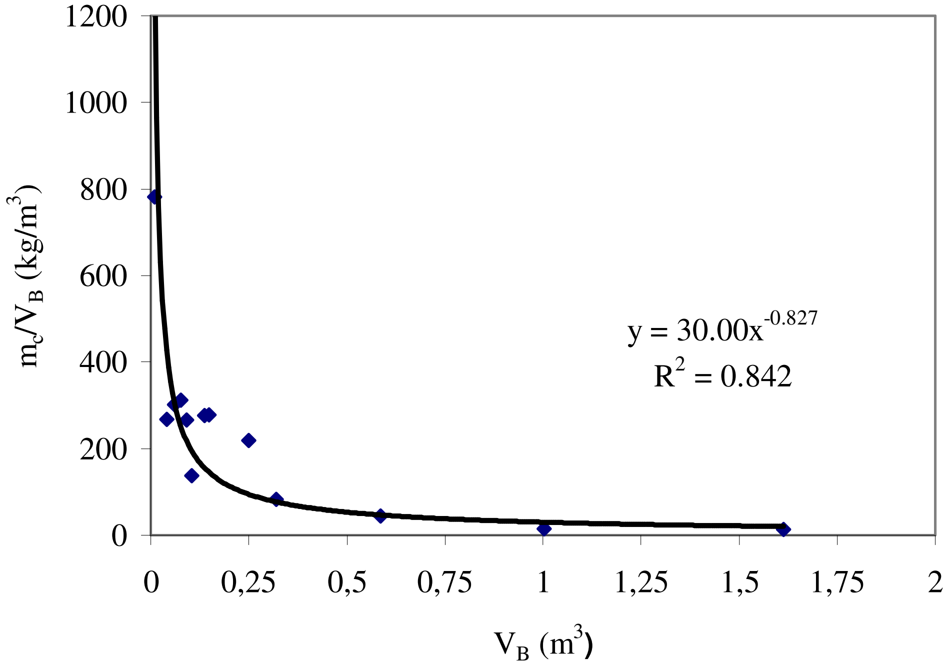

Figure 8 – Variation of the ratio mass of charcoal/burned volume as function of the burned volume for each of the selected plots (Source: Carvalho et al., 2006).

7. Changes of Composition of the Water Percolated through the Soil

The (disturbance) effects due to slash and burn of a forest plot on the chemical composition of soil water that percolates the soil top layer are studied. The work was also conducted at the Caiabi farm. Zero-tension lysimeters were installed at 20 cm depth to collect soil water samples from an evergreen primary forest (F) and from a slashed and burned area (B). The samples were collected fortnightly during three rainy periods named PER-I (September 1999 - January 2000), PER-II (October 2001 - April 2002) and PER-III (September 2002 - January 2003). The burning experiments were performed in August 1999. The solutes analyzed were: Na^+, K^+, Mg^{2+}, Ca^{2+}, NH_4^+, Cl^-, NO_3^- and SO_4^{2-}. Factor analysis applied to the forest data set produced three factors, explaining 85% of the variance. Factor one was associated with exchange processes in the soil and explains 38% of the variance, while factors two and three were attributed to biological processes (high load on NH_4^+ and NO_3^-) and leaching (high load on Cl^-), respectively. In general, in the burned site, for all chemicals except Cl^- and SO_4^{2-}, there was a pulse on the concentration values following the burning (PER-I), with a subsequent decay observed on PER-II, which reached the forest values during PER-III. Thus, two years after the burning, the solutes content in soil water decayed to values near, or lower, than the ones found in the forest. It is most likely that an intense leaching through the top soil occurs just after the burning, followed by absorption due to vegetation regrowth.

To install the lysimeters, two trenches 1.5 m wide, 2.5 m long and 1.0 m deep, one in the forest area and the other in the slash and burn experiment area, were dug. The observational period lasted from September 1999 until February 2003 and was divided in tree intervals named PERI (from September 1999 until January 2000), PERII (from October 2001 until April 2002) and PERIII (from September 2002 until February 2003), which were the rainiest intervals during the period considered.

Each lysimeter is composed of a 628 cm^2 polyethylene tray inserted in the soil through the sidewalls of the trenches in the natural forest and in the slashed and burned ones. The tray was connected with a hose to a 1 – liter container to collect the soil water samples. The samples were collected fortnightly and, at each collection time, the container was substituted with a clean one. Due to logistic problems that could lead to sample contamination, it was not possible to measure the collected volume.

Each sample of collected soil water was vacuum filtered to remove suspended solids and microorganisms using pre-washed Millipore membrane filters with 0.22 μm of pore diameter. After filtering, the samples were separated into two 30 ml aliquots: (i) for the major anions determination, stored in a high-density polyethylene bottle without preserver and (ii) for the major cations, stored in a polyethylene bottle acidified with 0.1% high-purity chloridric acid. All aliquots were stored at 4^o C until analysis.

The ionic species were determined with a Dionex DX-500 liquid-ion-chromatograph in the NUPEGEL-ESALQ/USP Laboratory (Nucleus for Research in Geochemistry and Geophysical of the Lithosphere - Luiz de Queiroz Agricultural Superior School/University of São Paulo in Piracicaba, São Paulo). For the determination of the basic cations and ammonium, a CS12 analytical column with sulfuric acid as the eluent was used. For the anions, an AS4A analytical column with sodium carbonate/bicarbonate as the eluent was used.

This study showed that the solute contents in the soil water present a concentration peak soon after the slash and burn of the forest, with values up to 80 times larger than those observed in the natural forest. Two years after this pulse, the solute content decays to values lower than the ones observed in the natural forest soil water. This happens because the burned area, which is surrounded by forest, is quickly recolonized by regrowth of secondary vegetation that most likely has high productivity and nutrient storage rate. The observed annual variations in the leaching of solutes through soil water at 20 cm depth for the natural forest are due to the hydrological variations within the soil. In the burned area, even considering the uncertainties in the estimated values, the solute content variations can be attributed firstly to a lack of biological activities and plant uptake and subsequently to the vigorous vegetation regrowth. The conclusion from these results is that, within the first months after the slash and burn of the forest, an intense leaching of nutrients through the soil profile occurs, eventually contributing to an abnormal input of nutrients to the top soil. However, this process is attenuated in time, and in two years, the soil water chemical content reaches values equivalent to the ones observed in the natural forest soil water.

8. Mercury Emissions by Fires

Several recent studies have indicated that forest fires are likely to re-emit important quantities of atmospherically deposited mercury (Hg) to the atmosphere. Although the Amazon forest accounts for approximately 25% of the world´s total rainforest, few data are available about these emissions. The emissions of mercury from prescribed fires of two 4-ha plots of Amazon forest were investigated. Hg concentration and Hg burden were determined for vegetation, litter and soil before and after the fires. The data show that only Hg present in the aboveground vegetation and in the O-horizon was volatilised; no significant soil emission was observed. Before the fire, the Hg stored in the vegetation (logs, branches, leaves and litter) ranged from 3.7 to 4.0 g ha^{-1} while 1.8 g ha^{-1} was found in the O-horizon. The mass balance calculations of the present work indicate an average Hg emission of 3.5 g ha^{-1} due to forest fires, with 1.6 ha^{-1} originating from O-horizon and 1.9 from above ground vegetation. On the base of the average annual deforestation rate of the Brazilian Amazon between 2000 and 2008, an annual Hg emission of 6.7 Mg yr^{-1} was estimated.

9. Newly Approved Thematic Project

Support to continue research on the subject of Biomass Combustion on Tropical Forests was approved for the period 2009 - 2013 from the Fundação de Amparo à Pesquisa do Estado de São Paulo (thematic project 08/04490-4).

The main objective of this thematic project is to congregate a multi-disciplinary team to investigate parameters relative to biomass combustion in the Amazon region and its emissions. In order to achieve the main objective, the research activities will be conducted in 2009 and 2011 in the town of Cruzeiro do Sul, Acre, and, in 2010, in the Caiabi Farm, in the town of Alta Floresta, Mato Grosso.

The first theme is “Monitoring of Physical Alterations in Changes of Soil Use with Slash and Burning in the Brazilian Occidental Amazon Region”. The objectives are to estimate carbon stocks in the soil before and after biomass combustion and investigate the presence of charcoal and micro-fossils in the soil profile.

The second theme is the “Determination of Indexes that Quantify Inhalable Particulate Material Emitted by the Burning of Amazon Biomass”. Among the several proposed activities, there is the sampling of particulate pollutants during the burning of forest biomass in the field and in laboratory experiments.

The third theme is “Determination of Emission Factors and Combustion Efficiency through Gas Sampling in the Field and in Laboratory”. The group has previous previous experience in this subject through activities already conducted in the Caiabi Farm.

The fourth specific theme is the “Obtainment of Parameters that Characterize Surface Fire Propagation in the Amazon Region Tropical Forest”. The research will be developed in the field and in laboratory. The objectives include the characterization of the typical surface fuel, the evaluation of the fire thermo-physical aspects and the estimation of CO, CO_2 and unburned hydrocarbons (UHC) emissions during the propagation of surface fires.

The “Obtainment of Parameters for Evaluation of the Numerical Model Developed for Plume Rise by the Center for Weather Forecast and Climate Studies (CPTEC) of the National Space Research Institute (INPE)” is the fifth specific theme of this project. The objective is the inclusion of transport mechanisms in climate, weather forecast and air quality numerical models. These mechanisms are directly dependent on gas and aerosol emissions, and they possess a strong initial fluctuation associated to the biomass combustion activity. This activity will be conducted only in the region of Alta Floresta and it will have support of INPE´s research airplane.

The sixth theme is “Natural Regeneration in Natural Areas and Secondary Succession in Burned Areas in the Occidental Amazon Region”. The activities will be developed only in Cruzeiro do Sul, Acre. This theme will count on prior experience on similar research conducted in the Caiabi Farm under FAPESP project 98/00104-9. The main objective is to compare, based on ecological parameters, different areas under secondary succession after felling of trees and setting of fire.

The next three are themes correlated to the main thematic of this project, and they will take advantage of the infrastructure to be implanted.

The seventh theme is the “Study of Biomass Burning Effects on Soil Fungi Biodiversity in the Amazon Region”. This research will be conducted only in Cruzeiro do Sul. The main objective is to acquire knowledge on the effects of primary forest combustion on the soil fungi biodiversity, comparing the biotic diversity before, during and after combustion. It should be mentioned that these studies attend the necessities of the region, due to the high existing and non characterized biodiversity. The results of such research will provide subsides for soil utilization with maintenance of the region micro-biota.

The “Evaluation of Fire Effects on the Fauna of Amphibians in a Natural Environment in the Town of Cruzeiro do Sul, Acre” is the eighth specific theme of the thematic project. The main objectives are to investigate the effect of the habitat destruction by fire on the natural amphibian and reptile populations and to describe the process of re-colonization of the affected areas.

The ninth theme is the “Validation of the Utilization of Sentinel Units, by the VIGIAR Program, as a Form of Data Capture Relative to Health Effects by the Alteration of the Air Quality in Regions of Biomass Burning”. It should be mentioned that the Brazilian Ministry of Health, by means of its Secretary of Health Vigilance and General Coordination on Environment Health Vigilance, implanted the Environment Health Vigilance Program – VIGIAR. It is task of the VIGIAR to furnish elements to orient national policies and population health protection areas regarding risks of atmospheric pollution.

In order to attain all the objectives of this multidisciplinary research, several researchers with distinct specialties were congregated from several Brazilian institutions: Universidade Estadual Paulista (UNESP), Instituto Nacional de Pesquisas Espaciais (INPE), Universidade de São Paulo (USP), Universidade Federal do Acre (UFAC), Universidade de Brasília (UnB), Universidade de Taubaté (UNITAU), and Fundação Universidade Federal do Rio Grande. Additionally, there will be collaboration from the following foreign institutions: University of Washington and United States Forest Service.

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