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Atmospheric Chemistry and Physics Discussions

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10, C4584–C4592, 2010

Interactive Comment

Interactive comment on "Moisture effects on carbon and nitrogen emission from burning of wildland biomass" *by* L.-W. A. Chen et al.

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We appreciate the reviewer's time and comments. Issues of measurement uncertainty have been addressed in our response to the other reviewer. Other issues are addressed in the following responses.

Specific comments (by page and line number): 1) Page 7988, line 15 – It is unclear what is meant by _50 bulk materials were collected. Is this the count of material (e.g. 50 individual leaves, needles, stems, branches etc.), or the number of individual locations where a sample is collected (e.g. a scoop or sweeping of the surface)? Were there criteria for what was collected or excluded (e.g. only items below a certain size or weight) and roughly how much material is collected within each plot (e.g. a few grams or kilograms)?

<Response> We have added the following descriptions to clarify the sample collection– "Within each of the plots, downed materials in a 20 x 20 cm2 area, 5 cm deep bulk volume were acquired from the forest floor at 12 randomly selected coordinates for a total of 6 – 8 kilograms of materials"– in Section 1, 1st paragraph. There were not particular size selections. The "50" bulk materials in the original manuscript included downed materials and standing shrubs.

2) Page 7989, line 1 – The authors should clarify what they mean by plant samples in the sentence beginning "Moisture content of plant samples: : :" Do they mean those collected from living plants?

<Response> Yes, this has been clarified to: "Moisture contents of aboveground shrub samples. . .".

3) Page 7989, lines16 to 22 – The text indicates that samples were kept warm prior to and during the combustion experiment by being on a hot plate with adjustable temperatures up to 500 oC, but it doesn't indicate the temperature of the hot plate and the duration of sample heating prior to combustion. Given that the primary independent variable is the moisture content of the biomass fuel, the potential of this warming to change the moisture content of the fuel prior to combustion should be addressed with additional information. 4) Page 7991, lines 1 to 12 – This text qualitatively describes the differences between dry and moist fuels during the combustion process. It would be much more informative if the authors provided more specific information. For example how long did it typically take for the ignition of the dry and moist fuel? Was the hot air igniter used for the same amount of time on each sample or was it kept on longer for the moist fuel longer (e.g., until it flamed)?

<Response> Descriptions have been added to the paragraph– "Fuels were placed on the hotplate (maintained at 450 degC) for $\sim$30 seconds before starting to be ignited by an electric hot-air gun (Looft Lighter). It often required continued application of hot air ($\sim$600 degC) for an extensive period of time to ignite and sustain combustion

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for high moisture fuels. The use of hot air gun minimized interferences from igniter (e.g., propane torch) emissions"– in Section 2, 4th paragraph. Both hotplate and hot air gun were used to achieve the ignition temperature. For dry fuels, flames started immediately with the hot air. We agree that the brief heating before ignition may change the fuel moisture content, but we did this uniformly for all the samples.

5) Page 7993, line 10 and page 7994, line 1 – These two lines contain acronyms OPN and GTC that I couldn't find spelled out anywhere in the text. Given the numbers of such acronyms used in this paper, a complete list should be provided somewhere in the text.

<Response> OPN and GTC were indeed defined earlier in the Method section– "The concentration ratio of a measured species over grand total carbon (GTC) released from a burn defines the emission factor (EF) of that species in, e.g., gram per kilogram of carbon burned, which can be scaled to gram per kilogram of fuel consumed with known carbon content of the fuel. GTC includes C in CO2, CO, and PM2.5"– in Section 2, 7th paragraph.

"Other particulate nitrogen (OPN, particulate N less those in NO3- and NH4+) EFs increase with fuel moisture content (Figure 3) and are particularly high (> 3 g/kgC and up to 75% of N in NH3) when burning wet duff and leaves (see moisture level II and III in Table 1)" – in the Section 3.2, 1st paragraph.

Considering that most of the acronyms in the paper are wildly used, except GTC and OPN, we did not create a table (and take a page) to list all the acronyms.

6) Page 7994, line 19 & 20 – There's something wrong with the wording of the sentence "High thermal energy in the flames allows to break up plant organic matter:" Maybe the word "it" should be added after "allows".

<Response> This sentence has been revised to– "High temperatures in the flames provide sufficient thermal energy to break up plant organic matter into small

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fragments,. . .”– in Section 3.3, 2nd paragraph.

7) Page 7994, line 23 – The use of the word “weakens” with respect to thermal energy doesn’t seem correct. “A better choice of a word might be “decreases”. However more generally for this discussion isn’t it more scientifically correct to discuss it in terms of higher and lower temperatures needed to affect the various reactions instead of thermal energy?

<Response> We changed the word “weakens” to “decreases” as the reviewer suggested. We believe that high temperature provides sufficient thermal energy to break up plant organic matter into small fragments.

8) Page 8002, Table 1 – From the footnote I understand that this table is populated with mean values from two separate burns for each fuel and moisture level. The footnote indicates that if the two values differ by more than a factor of 3, the greater uncertainty of the mean is indicated by the values being shown in brackets. It seems reasonable o suspect that the cause of such large uncertainty is the result of fuel inhomogeneity of the replicate burns, as opposed to problems of analytical accuracy/precision. The use of brackets to flag highly uncertain values is only modestly helpful when dealing with only a pair of measurements of a population that may have a large distribution. Minimum numbers of replicates to estimate the underlying variability of a parameter is generally considered to be between 4 and 7. Compounding the issue of publishing a table with values of unknown precision is the fact that the values are displayed with up to four significant digits, inappropriately implying a high degree of precision. Based on my inspection of Table 1, it appears that there is insufficient evidence for a difference between the smoke composition values for moisture levels II and III. If the authors agreed with this observation, they should combine the two pairs of measurements in order to calculate and report mean values and their standard deviations of the 4 replicates. Similarly the authors may be able to combine other sets of data (e.g. leaves and stems or plant species) to increase the numbers of measurements used to calculate means and standard deviations. In fact the only result differences that seem to be sub-

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stantive are between dry and moist fuels, and among litter, duff, soil and above ground plants.

<Response> First, we calculated the standard deviation of EFs from the two replicate burns and included them in Table 1. Although two replicate burns are probably not sufficient, these numbers provide some ideas of uncertainties in the reported EFs. A study of much larger scale, i.e., FLAME II (McMeeking et al. 2009), was also based on 2 replicate burns. We created a new figure (Figure 3) to illustrate the dependence of EFs on moisture content. In Figure 3, we do combine all the leaf and stem burns to increase the number of samples to 6 for each moisture level. The moisture effect (i.e., trend) on leaf and duff burns is clear even considering the uncertainties. Therefore, we decided not to further combine the two wet moisture levels together.

9) The number of significant digits used in the resulting tables should be made consistent with the precision indicated by the standard deviations (e.g., it's misleading to have more than 2 significant digits if the standard deviation exceeds 10% of the mean value; or 1 significant digit if the standard deviation exceeds the mean).

<Response> Although the standard deviations are shown in Table 1, they mostly reflect the natural variability of combustion emissions. The significant digits of these values should depend on the analytical precision. The analytical precision in this study is comparable to those of Chen et al. (2007) and McMeeking et al. (2009), and therefore we made the significant digits consistent with the two studies.

References

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Interactive comment on Atmos. Chem. Phys. Discuss., 10, 7985, 2010.

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Table 1. Time-integrated combustion efficiency (*CE*) and emission factors[a] for major C and N species as well as $PM_{2.5}$ from controlled burning experiments.

Plant Species		Downed Material			Aboveground Shrub					
		Composite			Bitterbrush		Manzanita		Squaw Carpet	
Parameter\Fuel Type		Litter	Duff	Soil	Leaves	Stems	Leaves	Stems	Leaves	Stems
Moisture Level I (Dry[f])	Carbon %[b]	*50%*	*32%*	*3%*	*52%*	*48%*	*49%*	*48%*	*47%*	*50%*
	Burned %[c]	*92%*	*52%*	*9%*	*92%*	*81%*	*90%*	*98%*	*83%*	*93%*
	CE	*0.94 ± 0.01*	*0.92 ± 0.02*	*0.86 ± 0.02*	*0.93 ± 0.01*	*0.94 ± 0.00*	*0.91 ± 0.01*	*0.94 ± 0.00*	*0.92 ± 0.01*	*0.92 ± 0.00*
	CO	126.2 ± 12.7	140.6 ± 27.3	297.3 ± 48.2	112.6 ± 30.3	127.4 ± 8.8	113.2 ± 43.5	128.4 ± 6.7	144.5 ± 22.3	162.1 ± 8.9
	OC[e]	2.5 ± 0.2	9.3 ± 6.7	14.9 ± 4.4	9.1 ± 1.8	6.4 ± 2.0	21.2 ± 7.9	5.5 ± 0.6	11.3 ± 0.2	4.7 ± 0.1
	EC[e]	4.6 ± 0.3	5.7 ± 0.1	0.7 ± 0.2	15.4 ± 2.7	2.9 ± 0.3	15.9 ± 3.9	2.0 ± 0.4	8.1 ± 0.8	2.5 ± 0.5
	$PM_{2.5}$[e]	8.1 ± 0.9	18.3 ± 10.2	N.D.	27.1 ± 5.8	13.0 ± 3.9	47.5 ± 14.1	8.7 ± 0.4	25.3 ± 3.2	14.5 ± 1.1
	NO_x	5.9 ± 0.3	4.9 ± 0.9	0.9 ± 0.2	9.1 ± 2.8	9.1 ± 1.0	7.1 ± 3.0	5.4 ± 1.0	7.7 ± 1.5	10.5 ± 0.8
	NH_3[e]	1.3 ± 1.1	3.7 ± 2.4	11.5 ± 6.1	7.7 ± 2.4	3.4 ± 0.6	4.0 ± 1.6	1.9 ± 0.8	6.8 ± 1.6	5.6 ± 0.1
	NO_3^-[e]	0.04 ± 0.01	0.03 ± 0.02	N.D.	0.05 ± 0.01	0.12 ± 0.00	0.16 ± 0.04	0.12 ± 0.00	0.07 ± 0.00	0.09 ± 0.02
	NH_4^+[e]	0.05 ± 0.01	0.06 ± 0.03	N.D.	0.04 ± 0.00	0.04 ± 0.01	0.04 ± 0.00	0.03 ± 0.00	0.05 ± 0.00	0.08 ± 0.00
	OPN[e]	0.24 ± 0.19	0.44 ± 0.35	0.31 ± 0.23	0.40 ± 0.11	0.31 ± 0.12	0.47 ± 0.21	0.09 ± 0.03	0.45 ± 0.04	0.28 ± 0.01
Moisture Level II	Moisture[d]	*10%*	*10%*	*10%*	*73%*	*39%*	*40%*	*39%*	*48%*	*44%*
	Burned %[c]	*72%*	*47%*	*10%*	*88%*	*66%*	*73%*	*53%*	*69%*	*92%*
	CE	*0.79 ± 0.06*	*0.70 ± 0.07*	*0.80 ± 0.06*	*0.88 ± 0.01*	*0.82 ± 0.06*	*0.72 ± 0.03*	*0.86 ± 0.11*	*0.67 ± 0.09*	*0.86 ± 0.06*
	CO	253.2 ± 59.8	444.9 ± 68.1	431.4 ± 143.8	113.2 ± 42.4	261.3 ± 44.0	97.5 ± 76.7	107.1 ± 2.4	77.7 ± 57.7	108.1 ± 96.0
	OC[e]	99.8 ± 34.9	110.9 ± 41.5	17.5 ± 1.0	66.1 ± 9.9	66.6 ± 36.1	236.0 ± 62.4	62.8 ± 64.1	292.2 ± 115.1	92.6 ± 18.4
	EC[e]	5.2 ± 0.3	1.0 ± 0.1	1.5 ± 0.5	7.3 ± 4.0	3.7 ± 0.7	5.6 ± 1.1	2.3 ± 1.2	8.5 ± 3.2	2.6 ± 0.3
	$PM_{2.5}$[e]	160.5 ± 56.2	143.9 ± 62.2	N.D.	96.9 ± 18.3	119.3 ± 73.7	214.9 ± 84.1	94.9 ± 91.3	270.8 ± 68.4	109.6 ± 32.7
	NO_x	6.4 ± 1.5	6.7 ± 1.4	2.8 ± 0.8	9.9 ± 4.0	13.0 ± 3.1	2.2 ± 2.9	2.9 ± 1.2	4.0 ± 5.4	10.7 ± 7.9
	NH_3[e]	4.3 ± 1.7	26.7 ± 14.0	24.7 ± 6.6	10.2 ± 1.5	10.7 ± 0.9	10.0 ± 0.5	3.8 ± 0.5	11.9 ± 4.1	11.0 ± 5.4
	NO_3^-[e]	0.17 ± 0.00	0.13 ± 0.01	N.D.	0.23 ± 0.02	0.20 ± 0.02	0.08 ± 0.03	0.08 ± 0.01	0.23 ± 0.04	0.20 ± 0.01
	NH_4^+[e]	0.24 ± 0.04	0.15 ± 0.01	N.D.	0.10 ± 0.00	0.03 ± 0.02	0.31 ± 0.09	0.05 ± 0.06	0.28 ± 0.11	0.06 ± 0.01
	OPN[e]	1.62 ± 0.59	3.57 ± 1.50	0.99 ± 0.26	2.03 ± 0.05	1.39 ± 0.68	4.4 ± 1.42	1.07 ± 1.33	7.70 ± 3.28	2.17 ± 0.46
Moisture Level III	Moisture[d]	*20%*	*20%*	*20%*	*84%*	*57%*	*60%*	*52%*	*66%*	*57%*
	Burned %[c]	*80%*	*45%*	*9%*	*86%*	*78%*	*68%*	*92%*	*65%*	*90%*
	CE	*0.74 ± 0.10*	*0.69 ± 0.07*	*0.82 ± 0.01*	*0.51 ± 0.07*	*0.84 ± 0.04*	*0.62 ± 0.09*	*0.87 ± 0.00*	*0.72 ± 0.01*	*0.88 ± 0.08*
	CO	313.6 ± 105.8	407.6 ± 29.2	357.7 ± 15.9	215.6 ± 31.1	216.8 ± 60.4	134.2 ± 43.5	188.5 ± 25.1	142.6 ± 22.3	133.1 ± 102.6
	OC[e]	116.6 ± 48.8	131.1 ± 59.2	22.1 ± 0.8	393.6 ± 54.1	67.8 ± 11.1	315.3 ± 111.1	43.1 ± 5.8	210.4 ± 20.2	61.5 ± 39.7
	EC[e]	7.6 ± 4.9	1.1 ± 0.2	2.3 ± 0.9	5.3 ± 0.5	3.6 ± 0.1	7.7 ± 1.3	2.6 ± 1.0	4.8 ± 0.0	2.7 ± 0.7
	$PM_{2.5}$[e]	179.9 ± 54.7	208.9 ± 56.2	N.D.	768.7 ± 43.2	99.5 ± 4.4	493.8 ± 231.9	61.5 ± 3.8	387.2 ± 31.1	129.1 ± 43.5
	NO_x	8.4 ± 2.5	3.8 ± 0.2	5.4 ± 0.1	9.6 ± 2.0	7.5 ± 0.5	2.7 ± 2.0	4.7 ± 0.5	6.4 ± 2.2	9.1 ± 2.3
	NH_3[e]	5.3 ± 0.4	17.7 ± 5.9	24.5 ± 18.0	19.1 ± 1.4	10.9 ± 1.8	10.1 ± 0.4	3.8 ± 0.0	9.5 ± 0.8	9.7 ± 4.9
	NO_3^-[e]	0.20 ± 0.05	0.09 ± 0.03	N.D.	0.28 ± 0.11	0.18 ± 0.02	0.12 ± 0.00	0.11 ± 0.01	0.14 ± 0.03	0.13 ± 0.08
	NH_4^+[e]	0.30 ± 0.11	0.15 ± 0.06	N.D.	0.32 ± 0.11	0.06 ± 0.01	0.42 ± 0.14	0.07 ± 0.01	0.18 ± 0.00	0.05 ± 0.03
	OPN[e]	1.59 ± 0.56	3.36 ± 1.40	0.60 ± 0.07	11.83 ± 0.53	1.59 ± 0.39	4.32 ± 1.52	0.66 ± 0.04	4.43 ± 0.36	1.33 ± 0.76

Fig. 1. Revised Table 1.

[a] In g/kgC (g per kilogram of carbon burned). Values are based on the average and standard deviation of two replicate burns. N.D. indicates the species are below detection limit. Emission factors with higher variability (average/standard deviation < 2) are marked in red.

[b] Percentage of carbon in dry fuels.

[c] Combined percentage of dry fuel burned.

[d] Fuel moisture content in percentage.

[e] Filter measurements

[f] Moisture content < 5%.

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Fig. 2. Table 1 footnote.

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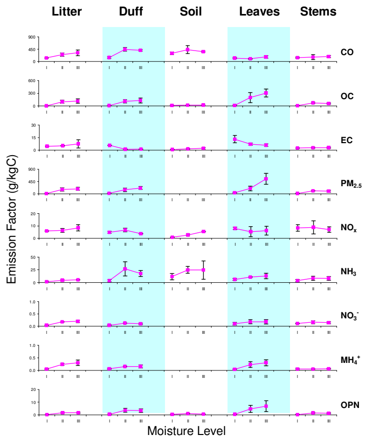

2 **Figure 3.** Emission factors, by fuel type, as a function of fuel moisture level, based on data
3 presented in Table 1 (all the leaf and stem data have been combined).

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Fig. 3. New Figure 3

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