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Interactive comment on "N_2O, NO, N_2, and CO_2 emissions from tropical savanna and grassland of Northern Australia: an incubation experiment with intact soil cores" *by* C. Werner et al.

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We thank Reviewer 2 for the comments and suggestions. We will outline how we improved the manuscript below (bold paragraphs are reviewers' comments, our response is given in plain text below).

General comments

The experimental design is a bit problematic with only one replicate native savanna and one grassland site. Moreover, these appears to be an unbalanced design with a transect with three locations at the savanna site and not at the grassland site. This is especially a concern given the marked differences in soil texture between the sites, i.e. the grassland site has lower sand and higher clay content. There should be some discussion of just how representative these sites are of savanna and grassland sites in the region.

The mentioned imbalance of sampling design was unfortunately a consequence of the overarching project setup. Large-scale spatial replication was not possible due the incubation setup and the resulting lab time (various SM and ST settings investigated with three different analytical systems). Although mentioned in the manuscript, we made this decision more visible for the reader.

We consider site T1 representative for the savanna found in the region under comparable hygric conditions (see e.g., Liveseley et al., 2011; Grover et al., 2013). Although located on slighly varying soil texture, we want to note that site T3 is representative for floodplain-based grasslands found in this area of the Northern Territory. We also feel that even when soil texture composition is slightly different to site T1, the selection of site T3 is warranted since the soil texture differences are withing site variance encountered in the area. Furthermore, landuse history is known for site T3 (Beatrice Hill Farm is a long-term state owned research farm) which is generally hard to find in this area. However, we added more discussion of soil texture properties and effects in the relevant section of the manuscript.

There also should be some discussion of just how much nitrogen gas flux is actually occurring at these sites. Some analysis of just how many days of high water content and high gas flux and how many "pulse events" actually occur

at these sites and how these interact to control the annual flux of these gases would greatly increase the relevance of the paper and allow the reader to evaluate just how robust the conclusions about the relative importance of the difference gases are.

We value this suggestion and decided to introduce a section covering this topic. To derive estimates for the average annual soil-atmosphere exchange of N_2O, NO, and N_2, a long-term time series of soil temperature and soil moisture readings are used (years 2001-2013, data provided by L. Hutley, from the long-term eddy flux tower site Howard Springs, located within 6 km of savanna site T1; soil texture and bulk density is comparable to T1 conditions, bd: 1.4-1.5 g cm^{-3}, sensors placed at 10 cm depth).

In order to obtain annual fluxes the data was classfied into discrete classes of SM and ST to enable the link with the incubation setup classification. Annual fluxes are the sum of daily emission for the extisting SM/ ST condition at this day. Finally, the annual estimates are averaged to acknowledge the inter-annual variability of hygric conditions of this region. On average, 58 % during any year were attributed to class M25T30 (ST <25$°C$, SM <37.5 % WFPS), followed by 36 % of class M50T30 (ST: 25-35$°C$, SM: 37.5-62.5 % WFPS). For only 14 days per year (or 4%) WFPS levels greater than 62.5 % WFPS (M75 conditions) were recorded at the site.

We present the flux rates without pulse emission contribution as a minimum scenario as we did not investigate the effect of consecutive watering/ drying cycles. The 13-year average of annual emissions (excluding pulse emissions) is estimated to ammount to 0.12 $\pm$ 0.02 kg N ha^{-1} yr^{-1} (N_2O), 0.68 $\pm$ 0.02 kg N ha^{-1} yr-1 (NO), 6.65 $\pm$ 1.07 kg N ha^{-1} (N_2), and 2718.96 $\pm$ 72.33 kg C ha^{-1} yr^{-1} (CO_2). When the relative contribution to gaseous nitrogen losses on an annual basis is considered it is very apparant that N_2

losses dominate the total (89 %), which N_2O only contributes 1.6 % and NO only 9.3 %.

Based on our set of measurements an additional contribution of 1.2 g N ha^{-1} yr^{-1} $event^{-1}$ (N_2O), 37.9 g N ha^{-1} yr^{-1} $event^{-1}$ (NO), and 22.2 kg C ha^{-1} yr^{-1} $event^{-1}$ (CO_2) can be derived. Since the actual number of pulse events is not known, we illustrate the potential contribution of pulse emissions by considering one to five 3-day pulse events. Our data suggests that pulse emissions contribute only 0.8-3.9 % and 1.0-3.9 % to annual CO_2 and N_2O emissions, respectively. The strong pulse emissions observed for NO fluxes are reflected in the potential contribution to annual NO emissions. For 1 to 5 pulse events they could contribute between 5.3 to 21.8 to total annual NO emissions. Due to the incubation setup limitation we could not measure and thus cannot report any potential N_2 pulse emissions.

The paper needs a thorough edit for English grammar and usage. A few examples from the very beginning of the paper are listed below. The entire paper needs to be edited. At Page 8401, Lines 23 – 25. This sentence is poorly worded and unclear. At Page 8401, line 26. "constraint" should be "constrained". At Page 8401, lines 14 – 16. Burn more frequently than ? At Page 8402, line 18. "these" is an unreferenced modifier.

A native speaker (co-author L. Hutley) will check the document for language quirks before upload. In response to the three examples given:

1. Changed to: *However, it is often difficult to find concise and clear criteria to define the spatial extent of this biome, and thus scientists often use a wide range of aeral estimates leading to substantial uncertainties in calculating the total contribution of this biome to the global soil-atmosphere exchange of nitrogen (Davidson and Kingerlee, 1997).*

2. *constraint* corrected to *constrained*
3. 8401 L14-16. More frequently as the average given for savanna in the sentence before. We rephrased the sentence to make this clearer.
4. *These* was intended to refer to tropical savanna ecosystems as they were discussed in the previous paragraph. To clarify, we replace it with *tropical savanna*.

Specific comments

- **Page 8403, lines 15-30. You've already discussed the idea that seasonal variation in moisture and fire and important in savannah ecosystems. Rather than repeating that here, maybe focus more on how this variation influences biogeochemical processes.**

  We removed the duplication here as suggested and rewrote the discussion of effects on biogeochemical processes (although, as suggested by Rev.1, we made sure to focus in aspects relevant to work and reffered the reader to relevant articles in the literature).

- **Maybe say a bit more about why measurements of N_2 fluxes are rare and why they might be important. Maybe move some of the text from page 8409, lines 17 – 24 up here.**

  As this was also pointed out by Rev.1, we extended the relevant section. As mentioned in our response to Rev.1, the lack of N_2 measurements is a consequence of methodological problems with the common acetylene-inhibition technique to quantify N_2 loss from soil (e. g., Felber et al. 2012). As stated in a recent review article by Butterbach-Bahl et al (2013), N_2 emission have been reliably quantified so far only for upland soils of 12 natural and agricultural ecosystem. This severe

lack of N_2 measurements currently strongly impedes our understanding of nitrogen biogeochemistry and mass balances from site to global scale. We extended this section as suggested and also consolidated the text from page 8409.

- **Page 8405, lines 7-13. The English grammar and usage are very rough here.**

  This sentence was indeed very awkward. We therefore changed it from: *The inter-annual variability of wet season intensity and total rainfall is quite substantially, as it is linked to large-scale circulation systems of the Southern Hemisphere.* to:
  The intensity of the wet season as well as the total annual amount of rainfall varies substantially from year to year.

- **Page 8405, lines 22-24. The vegetation has been described earlier, probably only need to describe it once.**

  Was removed as suggested.

- **Page 8406, line 10. Maybe include the scientific name for buffalo.**

  We added the scientific name: *Bubalus bubalis*.

- **It is not clear to me just when the N_2 flux measurements were made relative to the other measurements. Had the cores been help for many days and multiple water and temperature treatments before the N_2 flux measurements were made?**

  As stated at 8409 L22, N_2 analysis was carried out after the end of the incubation runs (N_2O, NO, CO_2 analysis). As the technique used to determine N_2 emission takes multiple days to complete a single measurement, we opted to pool soil from the three replicate cores used for any of the three soil moisture treatments (soil temperature was altered for one set of cores in consecutive steps as outline in the incubation illustration figure). We drew samples of soil from the soil cores after the incubation run was complete, mixed the substrate and rewetted the sample back to the desired soil moisture level. After waiting for the helium displacing the N_2 in the soil we started again a step-wise temperature increase for the sample and the given moisture setting. We acknowledge that this design might have the draw-back that the samples were previously exposed to different soil temperature conditions (as part of the incubation regime used to obtain N_2O, NO, CO_2 measurements), however they were always only exposed to a single soil moisture setting. We therefore do not report any possible N_2 pulse emissions as the substrate was setup for the soil moisture level for the previous analysis.

We extented the relevant paragraph to clarify this incubation setup design choice.

- **You might want to take a look at the recent review of N_2O consumption measurements; Schlesinger, W. H. 2013. An estimate of the global sink for nitrous oxide in soils. Global Change Biology 19:2929-2931.**

  We include the suggested citation.

- **Page 8417, line 23. It looks like there is a big difference in soil texture between the savanna and grassland sites. How might this have affected the results? I note that there is some discussion of the importance of clay content on page 8419. Also this might be a good place to mention that there is really only one replicate of each site type. There should be some discussion of just how representative of savanna and pasture systems these locations are. This is especially important for the grassland, where these is only one sampling location.**

  Indeed, the two sites are based on soils with slightly different textural composition. Although both sites feature a dominant sand fraction, clay content on site T3 is 10% higher. This does have implications as it should enhance soil moisture

retention and lead to lower O_2 saturation of the profile leading to more anaerobic microsites which should lead to stronger dentrification (and thus higher N_2O and esp. N_2 emissions). We enhanced the discussion section to acknowledge these circumstances. We also added discussion about how representative the sites are (as mentioned before we would argue that both sites are typical for this region). Grazing is common on the floodplain soils of the region and T1 features soil properties which are very similar to study sites previously investigated (see e.g., Livesley et al., 2011). We also do acknowledge, that no true site replicates are presented for grassland. This was a deliberate decission since a) the major focus of the study (and indeed the overarching project) was for N cycling on natural savanna and b) the time constrains on managing replicates in the suggested incubation setup did not allow for more replicates.

- **Page 8421, lines 22-28. Given the strong control of N_2 flux by soil moisture it would be important to add some discussion of how common high soil moisture levels are in this system. Just how many days of 75% WFPS do we get in these systems? How might this affect the very interesting conclusion that N_2 is the dominant gaseous product in these systems? This discussion and the subsequent discussion of pulse events raises interest in some estimates of annual emissions. Just how much nitrogen are you suggesting is leaving these systems as gas? How do these estimates compare with inputs from the atmosphere and fertilizer?**

  We enhanced the discussion regarding this topic by including the upscaling approach described previously (see response to general comments). We added a paragraph discussing the derived annual fluxes with general understanding of annual atmospheric N deposition (generally considered to be <2 kg N ha^{-1} yr^{-1}). The data suggests, that very high moisture levels only play a minor role in the annual totals.

- **Page 8424, point #5. This conclusion is weak due to the fact that there was only one pasture site. This conclusion should be “toned down” some.**

  We modified the conclusion as suggested.

Interactive comment on Biogeosciences Discuss., 11, 8399, 2014.

Table 1: Annual emission of N_2O, NO, N_2 and CO_2 (excluding contribution from pulse emission events). The number of days per year with a given soil temperature (ST) and soil moisture (SM) are presented together with the resulting annual emission rate. Note that no pulse emission events were considered when building annual sums.

	SM [% WFPS]	25	25	25	50	50	75	75	annual flux [kg C/ N ha^{-1} yr^{-1}]			
	ST [°C]	20	30	40	20	30	20	30	N_2O	NO	N_2	CO_2
Year	2001	0	205	0	0	152	0	8	0.10	0.68	5.48	2627.9
	2002	0	226	12	0	117	1	9	0.10	0.70	5.77	2691.8
	2003	0	223	13	0	99	1	29	0.14	0.69	8.52	2884.0
	2004	0	223	5	3	118	0	17	0.12	0.69	6.66	2748.0
	2005	0	213	2	0	147	0	3	0.09	0.69	4.77	2594.9
	2006	0	203	7	1	132	3	19	0.14	0.67	7.69	2748.0
	2007	0	233	0	0	111	2	19	0.13	0.69	7.39	2783.5
	2008	0	219	5	0	124	0	18	0.12	0.68	6.80	2754.2
	2009	0	223	7	0	120	0	15	0.11	0.69	6.38	2735.9
	2010	0	172	0	0	175	0	18	0.13	0.65	6.94	2673.3
	2011	10	176	0	0	156	3	20	0.14	0.65	8.03	2691.2
	2012	0	225	23	0	107	0	11	0.10	0.71	5.78	2724.0
	2013	0	207	0	0	144	0	14	0.12	0.67	6.30	2689.7
		1	211	6	0	131	1	15	0.12±0.02	0.68±0.02	6.65±1.07	2718.96±72.33

Fig. 1.