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Interactive comment on "The nitrogen, carbon and greenhouse gas budget of a grazed, cut and fertilised temperate grassland" *by* Stephanie K. Jones et al.

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general comment: We would like to thank the referee's comments. The novelty of our manuscript is related to the synthesis of a long dataset, which hasn't previously been undertaken in such detail over such a long timescale. We have addressed all specific comments.

specific comments:

Page 2, line 51: Insert 'from' here once again to make clear that it is all CH4 emission.

"from" has been inserted

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Page 4, line134: Well, this seems a bit awkward. Can you quantify this 'something', also for the temperature?

We apologise for this mistake, the actual standard deviations have been added (947 $\pm$ 234 mm, 9.0 $\pm$ 0.4 ÍęC)

Page 4, line136: perenne (do not start with capital P). It is unusual for permanent grassland to have such a clear dominance of one species. Are there any grassland renovation measures taken regularly?

Lolium Perenne has been changed to Lolium perenne. There have not been any grassland renovation measures taken place during the 9 years of presented measurements (2002-2010). The field has been ploughed and reseeded to improve the quality of the grassland, but only in March 2011.

Page 5, line 142: How large was the grassland area considered? What was the grazing management like? Rotational grazing? It seems rather erratic from Fig. 1, at least for heifers.

The size of the grassland field was 5.424 ha. The grazing management can be described as rotational grazing; The farmer moved animals from neighbouring fields to the Easter Bush field when the grass was high enough and then moved them back to neighbouring fields again when the grass was too short at the Easter Bush field to allow the recovery and growth of the pasture plants after grazing. This information has now been added and "grazed continuously" replaced with "grazed rotationally".

Page 5, line 148: Not at all in the later years?

Yes, the grass was not cut in all the later years

Page 5, line 151: Rephrase (application was applied)

The sentence has been changed to: "In 2008 an additional fifth mineral N application was added, using urea instead of ammonium nitrate fertiliser."

Page 6, line 173: Does this include animal excretion?

No, animal excretion is not included here as animal excretion is N that is recycled from plant and soil uptake.

Page 6 line 191: Similar for ewes with lamb.

We agree and included a sentence stating that ewes were not milked but their milk was only consumed by their lambs.

Page 6, line 193: As it appears here as output, I feel the excretion should also be taken account of as input to the soil. Although it is recycled from plant and soil uptake, it is returned to the system and part of it is lost as CH4 (or leaching). Otherwise, the balance would suggest that animals fed on the site (which is considered in the balance), but were removed (e.g. to a stable) for excretion. This was not the case, however.

Carbon lost as CH4 from animal excretion originates from C uptake from plants and is therefore included in the NEE, thus FCCO2. Therefore, if we counted C input from excretion as input, this C would be account for twice.

Page 7, line 232: What was the estimate based on? Did he weigh his trucks before going into the silo? Was it estimated by plant height and density?

The farmer estimated the harvest amount based on information from plot experiments with similar management in the area, taking the plant height of the grass at Easter Bush at the time of cutting into account.

Page 7, line 239: Were they weighed again at the end/before giving birth?

Heifers were weight before they came onto the field and again at the end of the season, when they left the field.

Page 7, line 240: How realistic is the assumption of constant weight when they are lactating?

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Most ewes will lose weight during lactation. However, as ewes were fed extra protein (standard cake-concentrate) to reduce weight loss during lactation, we assumed a constant weight. The information that the ewes received extra feed during lactation is now added in the paper.

Page 8, line 242: Some of the weight of the lambs at least would be bones, though..

We agree with the referee. Using a bone content of 20 % for sheep (Lambe et al. 2007; Livestock Science 107, 37–52) and 14 % for Heifers (Navajas et al. 2010; Animal, 4:11, pp 1810–1817) and a C and N content of bones of 20 and 7 %, respectively (Marchand, R.F. (1842): Ueber die chemische Zusammensetzung der Knochen. Journal für praktische Chemie 27, 83–97. DOI: 10.1002/prac.18420270117), we corrected the C and N offtake of meat by including the bone content and adjusted values in table 4 and 5 and Figure 3 and 4.

Page 8, line 247: ...(Roche, 1995)‘

Roche J., 1995 has been changed to Roche, 1995

Page 8, line 253: Well, but this is where the leachate would go to...

The reviewer is right that the hollow terrain position likely receives inputs of water and leached nitrogen compounds from upper terrain positions. Inputs of water and nitrogen into the hollow terrain position likely occur via lateral flow of groundwater or capillary rise from shallow groundwater. Since we used a water balance model based on water holding capacity, information of the quantity of (ground) water that is transported in the hollow laterally or via capillary rise was not available. Therefore we restricted the quantification of leaching losses to the upslope position, where the downward movement of water and solutes prevailed. We have changed the description of water balance model (page 8, line 263) into: The latter was derived from a soil water model based on balancing daily precipitation and evaporation considering the water holding capacity of the soil (Kindler et al., 2011). This model did not allow the calculation of upward water

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fluxes with capillary rise from groundwater. We therefore only used the data for the upslope position for the calculation of leaching losses. The data of the hollow position were not used, because the soil was frequently water logged and likely influenced by capillaries from shallow groundwater and lateral flow of groundwater.

Page 8, line 256: How did you make sure there was no further mineralisation/denitrification in the samples before collection? Two to three weeks seem quite long time periods.

We agree that transformation of especially nitrogen species in sampling bottles before collection must be considered. Therefore, we placed the sampling bottles in an insulated aluminium box that was placed in a soil pit in order to keep the temperature of the sampling bottles as close as possible to the soil temperature and as cool as possible. We rejected the possibility of "poisoning" the leachate in the sampling bottles, because the addition of most poisoning agents like cyanide or strong acids (e.g. HCl) interferes with other analytical parameters, while the reliability of the reduction of microbial activity is questionable. Furthermore, we strived to minimize the use of harmful substances. Microbial transformations in the sampling bottles are also reduced by the fact that the leachate passes a filter with very fine pores, the suction cup (pore width $< 1.6\ \mu$m), before it enters the sampling bottle. In the case of our study, a loss of nitrogen via denitrification also is unlikely, since the flasks were flushed with oxygen-rich atmospheric air every two weeks and the evacuated sampling bottles contained a rest of oxygen-rich air, because the vacuum that was applied equalled only 40kPa. Therefore, the oxidation of ammonium to nitrate in the sampling bottles is in principle possible. This would mean that ammonium concentrations could be underestimated, while nitrate concentrations could be overestimated, without altering the total nitrogen concertation in the leachate and hence total nitrogen losses. The same applies to very biodegradable dissolved organic matter congaing organically-bound nitrogen (DON). However, we would like to note that these very biodegradable dissolved matter compounds as well as ammonium are commonly oxidized rapidly already in the soil.

Page 9, line 289: Annual rainfall was measured directly at Easter Bush?

Yes, the annual rainfall was measured directly at Easter Bush

Page 9, line 299: Close second bracket.

The missing bracket has been added.

Page 9, line 300: Unite references. IDEM = Integrated Deposition Model

The references have been united and the abbreviation of the model added

Page 9, line 306: When describing leaching measurement, you mention a slope, thus I suspect the area was not flat. How does this work with EC? How large was the area considered?

The maximum gradient in the field is 2.5 %, so although not completely flat, the topography is only gently sloping. The field has a mean slope is from NW to SE, with the steepest slope some 100 m to the NW of the flux tower. The mean flux footprint reflects the prevailing wind direction from the SW and secondarily from the NE, with the bulk of the contribution coming from within 50 m. The EC measurements thus sample the flatter areas of the field. Standard corrections are applied in processing to rotate coordinates relative to the mean wind flow in each half hour period. In this way, the fluxes are measured relative to the plane where mean vertical wind speed is zero, rather than assuming a horizontal ground surface. For these reasons, we do not think slope is a serious issue at this site.

Page 10, line 313: And to deposit excreta?

Yes, chambers were also accessible for animals to deposit excreta, if they wished to. This information has been added.

Page 10, line 317: How?

Samples were transferred from tedlar bags to glass vials by a syringe, which was fitted

with a three way tap. Glass vials were flushed with the samples using two needles (one fitted to the syringe and one stuck into the lid of the vial) in order not to over pressurise the vials. This information has been added.

Page 10. Line 325: calendar

Callendar has been changed to calendar

Page 10, line 326: Did you also simulate fluxes for the times you had data and compare the results with your measurements? How good was the fit?

LandscapeDNDC was tested in detail with available data on plant growth soil temperature, moisture, inorganic soil N concentration NO and N2O which resulted in general good agreement of simulations and measurements. Model simulations match the general pattern of high nitrate leaching (∼50 kg N ha-1) and N2O emissions (∼6 kg N ha-1 yr-1) as well as moderate NO emissions (∼2 kg N ha-1 yr-1). Results except NO emissions are published in Molina et al., 2016. (Molina-Herrera S, Haas E, Klatt S, Kraus D., Augustin J., Magliulo V., Tallec T., Ceschia E., Ammann C., Lubet B., Skiba U., Jones S., Brümmer C., Butterbach-Bahl,. Kiese R. 2016. A modeling study on mitigation of N2O emissions and NO3 leaching at different agricultural sites across Europe using Landscape DNDC. Science of the Total Environment 553, 128-140.) R^2 of simulated and measured daily soil temp and moisture are 0.6- 0.9. r^2 of soil inorganic N and N2O and NO are less good (<0.3) at daily time step but this is mostly related to the patchiness of emissions by grazing and deposition of urine and faces. Nevertheless, aggregating to longer time steps (monthly to yearly) increases r2 to values up to 0.5-0.8.

Page 10, line 343: area

Are has been changed to area

Page 10, line 344: Again, how did these compare to measured data?

Please see comment to Page 10, line 326.

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Page 11, line 353: This could have been measured easily. It will also change over the season. There are lots of assumptions in the dataset.

The N content in the grass has actually been measured monthly, although not in all years. Using those measured values to calculate CP we now re-calculated daily N excretions for ewes, lambs and heifers. For years, where no grass N content was measured we used an averaged value calculated over all years. We agree with the referee that there are many assumptions in the dataset. Unfortunately we didn't have funding to measure all C and N concentrations and fluxes within the grassland over 10 years to calculate a C and N budget, but the data were collected during three different projects (GREENGRASS, CarboEurope and NitroEurope), with each different objectives. Therefore gaps in measuring series were unavoidable.

Page 11, line 358: Add information that variation in excretion depends on variation in weight of the animals.

The information that the variation in excretion depends on weight variation has been added.

Page 12, line 384: Similar information is missing for N2O-EC data above.

Details for the gap filling method of N2O-EC data are described in Jones et al 2011. We have now added this reference referring to gap filling method.

Page 13, line 433: Did you still take them into account in the balances?

No we, did not take them into account as they were assumed to be negligible.

Page 18, line 583: Below, it is said that this is the value for grazed years, while it was 2 g less over all years. Please check.

It is correct that the value for 2004-2010, which is the period for which soil stock measurements are available, corresponds to the "grazed only" years (when no cut was carried out). Over all years the N storage from flux calculations is indeed 2 g less than

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for the period of 2004-2010, mainly because N was lost in 2002 (see table 4).

Page 18, line 583: Given the standard deviations, I guess there is no significant difference. So be careful not to overinterpret 'differences'.

We agree that there is no significant difference and therefore should not over interpret differences.

Page 19, line 634: Repetition from above.

The first sentence of 3.5 has been deleted and the GWP of CH4 and N2O included in the method section under 2.3

Page 19, line 644: Did you never measure uptake?

Yes, we did measure N2O uptake on occasional days (see Jones et al. 2011). But on an annual basis, we measured a net loss of N2O for each year and as budgets are presented annually we did not mention negative N2O fluxes.

Page 20, line 663: For trying to estimate whether the system is in equilibrium, it would be good to have data about grassland renovation/ reseeding etc. For a more than 20 year-old permanent grassland, a cover of 99% Lolium perenne is rarely found. If it was renovated in between (and maybe not so long before or even during the study), this would make more sense. However, in that case, the soil would have been disturbed (including mineralisation etc.) and a new equilibrium would have to be established.

There have not been any grassland renovation measures taken place during the 9 years of presented measurements (2002-2010) nor in the last 20 years. The field has been ploughed and reseeded to improve the quality of the grassland, but only in March 2011 (after the end of the period reported in this manuscript).

Page 21, line 684: Delete 'is'.

'is' has been deleted

Page 21, line 704: Where/on which scale?

The stated 85% are actually not crops but nitrogen in crops harvested or imported into the EU, whereas only 15 % is used to feed humans directly (Sutton et al. 2011). We apologise for this mistake and corrected the numbers and added the relevant reference in the text.

Page 21, line 706: Or a larger fraction of meat produced from grassland only.

We agree with the referee's comment and included this information.

Page 21, line 708: Delete ':'.

':' has been deleted

Page 23, line 759: Did you consider freeze-thaw cycles?

No, we did not specifically consider freeze-thaw cycles.

Page 23, line 769: IPCC No wonder, as there is a wealth of processes producing N2O in soils.

Yes, we appreciate that the processes producing N2O are complex. These are discussed in our and other papers we referred to in this manuscript.

Page 23, line 776: What are these two numbers? Minimum and maximum? Emission from mineral and organic fertilizer???

Those two numbers are minimum and maximum N2O emission factors shown in Table 6, whereas the maximum is actually 7.2 not 7.4%. This has been corrected and clarified.

Page 24, line 792: predominantly

'Predominately' has been change to 'predominantly'

Page 24, line 804: Please check sentence (text within/outside brackets).

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The sentence has been corrected.

Page 24, line 806: cattle-grazed?

‘cattle grazed’ has been changed to ‘cattle-grazed’

Page 24, line 817: ...for N losses.

‘from’ has been changed to ‘for’

Page 25, line 838: Well, the grass is used for feeding animals also if it is cut. Just the emissions are produced somewhere else.

We agree with the referee’s comment. However, as mentioned in section 2.3, we set the boundary for inputs and outputs for out budget by the field perimeters. Therefore emissions produced off the field are not included in the budget.

Page 25, line 848: If water and nutrients are not limiting.

This has information has been added.

Page 26, line 873: ...where...?

‘Whereas’ has been changed to ‘where’

Page 26, line 877: and CH4

‘and CH4’ has been added in the sentence

Page 27, line 893: comma should not be superscript.

Comma is now not superscript anymore

Page 27, line 897: I do not see the contradiction. Or do you mean ’where’ rather than ’whereas’?

Yes, we actually mean ‘where’, not ‘whereas’.

Page 27, line 899: Close bracket.

The bracket has been closed

Page 27, line 905: have been shown

'have shown' has been changed to 'have been shown'

Page 28, line 946: not be ...

'be' has been added after 'not'

Page 29, line 968: loose

'lose' has been changed to 'loose'

Page 30, line 998: If the total number of animals increases. If the same number of animals is just fed in a different way, changes in emissions are rather small.

We agree with the referee's comment and clarified this in the text.

Page 30, line 1007: Insert reference to Smith 2014, as this is nothing you showed in this study.

The reference of Smith 2014 has been inserted

Page 44, table 5: You give different numbers for all years. What do you mean with this? Or do you mean that the 2010 value is the average of 2002-2009? Then the asterisk after 'Leaching' is confusing.

The 2010 value is the average of 2002-2009, the asterisk after 'leaching' has been deleted

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