

Interactive comment on “Centennial black carbon turnover observed in a Russian steppe soil” by K. Hammes et al.

K. Hammes et al.

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Reviewer 2

1. Despite its high relevance and uniqueness I have two major concerns. Other possibilities that might also explain the observed differences in black carbon stocks must be ruled out or at least discussed in more detail.

1.1. The role of transport of black carbon out of the soil profile. The depth profile differs considerably between the three soil cores. Why is this? The authors should discuss the reasons for the differences across the soil depth and validate or argue that transport out of the profile is not a major concern.

The turnover time presented here is for loss by all processes: decomposition, leaching, and erosion. The rate of loss with respect to decomposition alone is slower than what-

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	OC Stock (kg m^{-2})		OC Concentration (g kg^{-1})	
	0-100 cm	0-5 cm	0-100 cm	0-5 cm
1900	31.1	2.7	48.4	105.3
Ave. Mod.	30.2	2.3	46.5	82.8
Std. dev.	3.7	0.4	4.5	15.1
Modern soils:				
1997	27.7	2.61	45.8	100.3
1997-2	28.3	2.38	51.4	74.0
2004	34.5	1.93	42.4	74.2

ever value we obtained for loss with respect to all processes combined. How much slower depends on how important leaching and erosion were. Our assumption in interpreting our results is that losses due to erosion and leaching were small, and the turnover time largely reflects the rate of decomposition. The more general statement is that the estimated turnover time is the cycling rate of BC in this soil with respect to all loss pathways.

Bioturbation is common in these steppe soils and could have contributed to variations in the BC depth profiles.

1.2. The spatial variability of black carbon stocks. How large is the spatial variability in soil carbon stocks? This issue is discussed only vaguely in the methods section. Is there data that could quantify the spatial variability? If not, the authors should statistically compare measures of variability of the recent cores with difference across time. This seems to be straightforward with Fig. 2.

Table of variation in OC stock and concentration for three modern profiles (1997, 1997-2 and 2004) compared to OC stock and concentration values for the archive soil (1900)

The OC stock for the archive soil falls in the range of that of the modern soils for the

	BC Stock (kg m^{-2})		BC Concentration (g kg^{-1})	
	0-100 cm	0-5 cm	0-100 cm	0-5 cm
1900	2.5	0.2	4.0	7.6
Ave. Mod.	2.0	0.2	3.2	5.6
Std. dev.	0.1	0.1	0.1	0.7
Modern soils:				
1997	1.9	0.1	3.2	5.1
2004	2.0	0.2	3.3	6.1

profile total and 0-5 cm. Torn et al. (2002) found no significant variation in carbon values when considering the whole profile, including the O horizon.

Table of variation in BC stock and concentration for two modern profiles (1997 and 2004) compared to BC stock and concentration values for the archive soil (1900)

The archive BC stock is higher than the range for the modern soils for the total profile. The 0-5 cm BC stock falls in the same range as that of the modern soils. 2. Further, I obtained slightly different turnover times. This is probably due to I did not correctly understood the scenarios of the best estimate and the min/max estimates. Suggestions to improve the description are given with the specific comments.

We have included a table in the Materials and Methods section that better explains the model (see Specific Comments point 12). We also added the derivation.

Specific comments

1. The abstract is well written, concise and presents the major message of the paper. It should be stated that other factors such as transport and spatial variability are no major concerns.

The abstract has been amended to include the following statement: The turnover time

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presented here is for loss by all processes, namely decomposition, leaching, and erosion, although the latter two were probably insignificant in this case.

2. P663 L4 "these studies" It is not clear which studies are referred to. State this more precisely such as "These incubation studies ...".

Agreed. We added the word "most"; (of these studies).

3. P661 L10-17 In my opinion not all the detail is required.

We have amended and shortened the paragraph:

Chernozems are the 8th most common soil order, covering approximately 7% of earth's ice-free land area (Bell and McDaniel, 2000). Nearly all of the 117 million ha of Chernozems in the Russian steppe are used for agriculture (Stolbovov and McCallum, 2002). Russian Chernozems have substantial organic carbon stocks of 28–34 kg m⁻² for the top 1 m under native (undisturbed) grassland (Mikhailova, 2006; Torn et al. 2002). Native Chernozem grasslands can be found only in a few preserves, including the Kamennaya Steppe Preserve created between 1882 and 1885 (51 00 N, 40 70 E, Lapenis et al. 2000).

4. P664 L9 "exactly the same location" A repeated destructive sampling at "exactly" the same location samples a disturbed soil.

This has been corrected in the paper and now reads "almost exactly"

5. In the cited Torn et al. 2002 I read that the location was narrowed down to "inside the microplateau of preserve 1" having an area of a few hectare. Do you have an estimate of spatial variability of C stocks and BC stocks within this area? It would be nice to report it at appropriate paragraphs.

A table with the OC stock values to compare 1900 with the modern profiles (1997_1, 1997_2 and 2004) has been drawn up (see above). There is no significant difference in carbon stocks but in BC stocks there is.

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6. Maybe this is not an issue with the steppe soil. However, with my experience on Central European forest soils spatial variability within a few meters often is an issue.

In our experience, the Russian Plains and US Mollisols with prairie vegetation sites that we have sampled were much less variable than were the forest sites we have sampled for C and bulk density.

7. P665 L14,15 "fairly representative": State this in more detail. If it is a summary of the following paragraph move it to the end of the paragraph.

We have rewritten the last sentence of the paragraph:

The watershed of the Kamennaya Steppe Preserve sits on aeolian deposits (yellow carbonate loess). Therefore, there is little spatial variation in the soil parent material, and the topography is very flat. The typical variation in height is on order of 5 m per km (except a few gullies). Replicate soil profiles sampled 1 km apart in 1997 had similar carbon content and horizon characteristics with depth (Table 1). We believe that the soil profiles sampled in 1900, 1997 and 2004, and analyzed here, are fairly representative of soil conditions under pristine steppe at the time of sampling, since the landscape is homogenous and there was little variation among replicate soil pits sampled in 1997.

8. P665 L18 "little spatial variation in the soil parent material": The reference to table 1 on Line 21 is not intuitive to the reader.

We amended this part of the manuscript to make the reference more clear:

The watershed of the Kamennaya Steppe Preserve sits on aeolian deposits (yellow carbonate loess). Therefore, there is little spatial variation in the soil parent material, and the topography is very flat. The typical variation in height is on order of 5 m per km (except a few gullies). Replicate soil profiles sampled 1 km apart in 1997 had similar carbon content and horizon characteristics with depth (Table 1).

9. Better present additionally a graph of the soil profile depth bulk densities and organic carbon with all soil cores together. Or quantify the variation as coefficient of variation

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or an adequate statistical measure.

We have added BC data to the table with the organic carbon values, and hope that addresses the suggestion. Table 1 contains for each profile (1) the depth increments, (2) bulk density values, (3) OC values and (4) ^{13}C data. The BC data has also been added.

10. P665 L24ff: I cannot judge the validity of the black carbon analysis based on my experience.

For black carbon analysis we used a molecular marker method quantifying benzene poly carboxylic acids (BPCA) specific for combustion residues, and released upon acid digestion in the lab. In a systematic methodological evaluation, this method has been found to be best suited for a conservative quantification of black carbon components in soil (Hammes et al. 2007). Additionally, this molecular marker method also provides information on the nature of BC beyond just an estimation of the amount, as it identifies and quantifies a number of BC markers that can be related to source and formation conditions of the BC.

11. P666 L19ff: The model is correct but described in a too concise way. I could follow the derivation only after a more detailed explanation. Maybe an appendix or online supplement is a good solution.

We have expanded the Methods and Materials Section to explain the derivation of the model.

12. P667 L12: I do not understand the numbers given for b. When trying to follow the described sensitivity analysis I obtained the following differing results. This may be due to that I did not correctly understand the scenarios of the best estimates and the min/max estimates. When I decrease bulk density for $S_0=2.5 \text{ kgC m}^{-2}$ by 10 percent so that initial stocks are only 2.25 kgC m^{-2} , I get for $S=1.9 \text{ kg m}^{-2}$ $b=0.84$. I suggest that the authors give used numbers for the scenarios in a table similar to the following

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one:

Reviewer: Scenario t f S0 b tau b tau S = 1.9 S = 2.0 Best estimate 100 0.1 2.5 0.76
322.4 0.80 397.9 Min. 94 0.1 2.75 0.69 223.4 0.73 260.4 Max. 102 0.0 2.25 0.84 603.2
0.89 866.0

We have amended the Methods and Material Section, the Results Section, Table 2, and Figure 5 and its legend to make the equations, the parameters, and the results more transparent. We appreciate the reviewer's comments on this section.

13. P668 L2: Why is the BC data presented as supplement and not with table 1? When you refer to the supplement state what the reader can expect to find. "Table of BC stocks with depth given in suppl. ..."

The BC concentration data were shown in Figure 1, and we have now added them to Table 1.

14. Fig. 1: It is hard to compare the inset graphs with the outer graphs. If not additional graph or measures of spatial variability is given, this is a severe drawback. Why is Fig1C missing the inset data of the 2004 soil? The integrated carbon stocks across the profile for the two recent cores are similar, however the depth distribution is not. Why this? Only the differences in depth between the 1997 core and the preserved are discussed in the text (P668 26ff). Legend of the fills or annotations directly in the graph would be helpful.

The reviewer is right that it is hard to compare the inset graphs with the outer graphs. They have been removed. They were sampled at a different time with different depth intervals and thus only total stock values can be compared with the other soils. These values are reported in the manuscript. Table 1 in the manuscript now includes OC and BC concentrations and bulk density for each soil depth increment that was sampled, giving the reader enough information to investigate the profiles, pedon-totals, and inter-site variability.

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15. P668 L20: In addition to the presented numbers refer to Fig 2.

This has been amended in the manuscript.

16. Fig 2: What do the error bars represent: standard error, 95percent confidence intervals? Is it correct that the error bars do not represent replicates at each plot but just the uncertainty of the analysis? It seems that you could easily compare the variability between the three recent ones with the difference across time.

The error bars represent standard deviation of measurements. There are no replicate soil samples to compare.

17. P668 26ff: You give a lot of citations of differences of BC with depth but no hypothesis or explanations about reasons. Possible explanations would be helpful to rule out the concerns referring to transport of BC out of the profile. I read in the cited Lapeinis 2008 paper that the soils became leached and I read about a strongly increased carbonate leaching. Can the BC be leached out of the profile together with the carbonate or is it just destabilized? On the other hand, if I assume a downward transport of BC and carbonate with increased precipitation then I would expect an opposite (downward) shift BC stocks in the profile. Did the intensity of bioturbation change with the management change?

The steppe in the Preserve underwent occasional, light grazing and some cut-and-removal of the vegetation, but there was no physical disturbance of the soil by tillage or vegetation type change. Krotavina, which are borrowing mammals, do occur in this ecosystem, and there were sparse channels in the soil-pit walls. There was no change in horizon depth intervals or horizon boundaries between archive and modern samples, which indicated that bioturbation had not changed dramatically. The plowed site was tilled.

The Results and Discussion Section discusses the possible linkage to loss of calcium.

18. P669 L15ff: You write about quality of BC, but in your text you write mostly about

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the degree of condensation. In the context of this paper I recommend to write more about recalcitrance or degradability, which is associated with the condensation and the chemical analysis. I found it hard to translate the BXCA labels to the context of quality and recalcitrance.

The figure caption of Figure 4 has been amended.

19. Fig. 3: A legend of the fills or annotations "1900" and "1997" directly in the graph would be really helpful. In the caption or legend indicate that B6CA is a slowly degradable fraction of BC.

Figure 3 has been amended.

20. P669 L24ff: You state an increase of proportion of B6CA, but Fig 3 shows this only for the upper 50 centimeters and the opposite below.

Probably there were two sources of confusion with the use of BPCA as molecular markers. First, the molecular markers (BPCA) are formed during analysis, those BPCA measured during analysis did not exist as BPCA in soil before. The BPCA are formed during acid digestion of soil when the aromatic fire-derived compounds are "cut in pieces" by the HNO₃ and the aromatic rings substituted with carboxylic groups. An aromatic ring on the edge of a black carbon structure will form a "three substitution" i.e. B3CA. Rings in the center of the structure, are six times substituted and forms the B6CA, and they are more protected against degradation than the rings on the outside. The highly condensed aromatic (and recalcitrant) core of black carbon structures produce relatively more B6CA molecules than those less condensed (and more decomposable) structures on the edge of the BC structure. Second, in Fig. 3 we show the relative contribution of B6Ca to the total of all BPCA. When the sum of all BPCA decrease but B6CA remain constant (as shown in Fig. 4) the relative contribution will increase.

21. P669 L25: "is evident". With current labeling of Fig.4 I had to assemble several

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pieces from the text together to follow your thoughts.

Figure 4 has been amended.

22. Fig. 4: Give a legend of the fills that matches the other description of the profiles. Do the light columns represent 1900 soil and the dark columns the 1997 or 2004 soil? On the x-Axis indicate the gradient of condensation and degradability. Part of the Y-axis label is clipped.

Figure 4 has been amended.

23. P670 L2ff: I obtain different results. See my comments on P667 L12. If the scenarios are described more clearly, they do not need to be repeated here.

A table has been created. See number 12.

24. P672 L3-8: What are the implications of calcium loss for the presented results and the conclusion? Is this an alternative for the decay or does it explain the observation of a fast decay? Will BC at locations without calcium loss have longer turnover times?

The presence of polyvalent cations, such as Ca, may help to stabilize soil organic matter, e.g. through Ca²⁺ bridges. This might also happen to fire residues but has only been documented once before in Clough and Skjemstad (2000).

Clough, A. and J.O. Skjemstad (2000), Physical and chemical protection of soil organic carbon in three agricultural soils with different contents of calcium carbonate. *Aust. J. Soil Res.*, 38(5), 1005-1016.

25. P673 L2: Before other explanations of the observed difference in BC stocks are ruled out, I would recommend to put the conclusion with more caution such as "it is likely that BC ..." or "based on the assumptions that the decay of BC is the single cause for the observed decrease of BC stocks ..."

The conclusion paragraph has been amended. See answer to Reviewer 1.

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Technical corrections

1. The DOI: 10.1029/2007GB003077 was not found by www.doi.org given with reference with Lapenis, A. G., Lawrence, G. B., Baily, S., Aparin, B. F., Shiklomanov, A. I., Speranskaya, N. A., Torn, M. S., and Calef, M.: Climatically driven loss of calcium in steppe soil as a sink for atmospheric carbon, *Glob. Biogeochem. Cy.*, doi:10.1029/2007GB003077, in press, 2008.

The paper has been published in *Global Biogeochem. Cycles*, 22, GB2010, doi:10.1029/2007GB003077.

Interactive comment on *Biogeosciences Discuss.*, 5, 661, 2008.

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