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Interactive comment on "Aggregates reduce transport distance of soil organic carbon: are our balances correct?" *by* Y. Hu and N. J. Kuhn

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Dear Referee:

Thank you very much for your time and comments. Your suggestions are appreciated and helpful to improve the manuscript. Below are our replies to the individual questions.

(1) As the authors already acknowledge, the data provided is very limited data for such large statements, nevertheless, they devote a large part of their discussion to discuss the global implications of their findings. Thus, I would suggest the authors to strongly reconsider the focus of their discussion and put their efforts into explaining the mechanisms behind their observations rather than drawing global conclusions with large uncertainties (not even quantified).

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Answer: We understand your concerns in terms of extrapolating data from a single soil type under certain simulated rainfalls to global scales. As stated in our manuscript, the potentially significant deposition of eroded SOC within the terrestrial system inferred from this study aims at illustrating the risk of overestimating the erosion-induced CO2 sink strength, rather than quantitatively determining the significance of such biased estimation. Similar concerns have also been raised by several other referees on the way the risk was calculated in this paper. However, Referee 9 also acknowledges that the estimation in this study is put in a proper perspective. Therefore, we would prefer to still draw attention to the comparison in the paper, but without too specific numbers to justify the uncertainty. In order to accurately deliver our statement, the relevant section will be changed in the revised manuscript:

“A 15.5% SOC enrichment of sediment re-deposited in the terrestrial system would imply a corresponding reduction in lateral SOC transfer between eroding and all colluvial depositional sites. The percentage of such enrichment corresponds to the proportion of eroded SOC estimated to be deposited in permanent sinks (e.g., 0.12 Pg yr-1 by van Oost et al. 2007). While the effects of aggregation on SOC redistribution and subsequent fate cannot be assessed based on one experiment, most sediment is transported in form of aggregates (Walling, 1988; Walling and Webb, 1990). Ignoring the effect of aggregation on erosion and redistribution of SOC, therefore, bears the risk of overestimating the erosion-induced carbon sink effect. As a consequence, the behavior of aggregated sediment requires a reconsideration of existing approaches. Further study of different soil types, their aggregation and aggregate breakdown while moving through landscapes of varying topography during rainfall events of different intensity, frequency and duration, is required to assess the relevance of aggregation for SOC movement and fate identified in this study.”

(2) In addition, the authors report that there were no differences in the particle size distribution of soil and sediments, contrary to what has been observed in other laboratory studies and field experiments. Given the fact that particles in the flume are moved

by interrill erosion, my guess would be that the flume might not be long enough for redeposition of large particles to occur during the transport phase and, thus, a selective transport of fine particles further on. On this behalf, were there signs of sediment deposition along the flume (and not only at the bottom collection point?) How would having a larger flume might have changed your results? Sediment arriving at colluvial sites in agricultural landscapes might often have traveled very large distances. Adding some explanation on how the methodological constraints which make an extrapolation of the results undesirable (p.e. slope gradient of 15%, leveling of the surface,: : :) might have affected the results would also contribute to strengthen the manuscript.

Answer: The 1.5 m long flume with a 15% gradient was particularly chosen to ensure sufficient runoff to initiate non-selective erosion on this particular silt loam (see section 2.1). Besides, the soil surface was levelled to exclude large roughness and depressions that might inhibit the movement of aggregates. Relevant text as following will be added into the revised manuscript: “During the simulated rainfall events, the sediments were seen to move continuously with runoff, and no evident selective deposition was observed on the soil surface.”

Using a longer flume might result in two reactions: 1) If the flume was extended with a flatter pathway, then the slowed down runoff would in theory result in even more significant preferential deposition of eroded sediments. 2) If extended with the same or even steeper gradient, then a longer slope would probably accelerate the speed of the runoff, thus improve the transport capacity of the runoff. In this case, the sediments transport would be more likely to be transported in form of aggregates rather than mineral particles, as a result of the combined effects of re-entrainment and preferential deposition (Beuselinck et al., 1999c). This would generally increase the transport distances of eroded sediment and the associated SOC.

In slope scale, previous research has pointed out that sediment delivery ratios are up to 90% smaller than soil erosion rates, even in catchments with soils of fine texture where all soil particles should move as suspended load (Walling, 1983; Beuselinck et

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al., 1999b, 1999c; Parsons et al., 2006). This demonstrates that most of the eroded sediments are re-deposited during transport processes (Beuselinck et al., 2000). There could be two possible explanations: 1) sediment is not eroded and transported as mineral particles, but in form of aggregates (Beuselinck et al., 1999c). Aggregates do not move that far as individual mineral particles, due to the accelerated settling velocity of aggregates by the greater masses and larger sizes. 2) Runoff is not always continuous, but of certain transport capacity. Preferential deposition occurs along the transport pathway, once sediment fractions are out of the transport capacity of runoff. These re-deposited fractions would then likely to be subjected to repeated erosion processes (Starr et al., 2000; Jacinthe et al., 2002; Lal et al., 2004; Lal and Pimentel, 2008).

In addition, we assume that the aggregate size distribution during prolonged transport processes would not change significantly. The proportional composition of the six EQS classes in each sediment collection interval did not significantly differ over rainfall time (ANOVA, single factor, $P > 0.05$, n=18). Experiments from another study (Xiao et al., in preparation) also show that increasing raindrop impact to aggregates, within a certain extent, does not reduce aggregate size distribution much more.

(3) I would also suggest the authors to look at the effect of sediment re-aggregation in future experiments. In relation to the respiration measurements, it would be interesting to have some insight into the quality of the SOC within each aggregate size class. Could smaller size particles respire less due to the fact that they contain older or more 'recalcitrant' SOC?

Answer: We agree with your comments. This study serves merely to identify the potential error introduced by the effects of aggregation on SOC redistribution, rather than quantitatively determining the significance of such an error. In the future, more experiments with soils of different aggregation and various SOC contents need to be carried out to examine the aggregation effects on the silty loam studied here to a wider range of soils. Long-term monitoring is also required to determine the mineralization potential

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of different SOC fractions. Further research should also focus on the effects of preferential deposition of eroded aggregates, and the fate of SOC in these aggregates, whilst in-transit towards downslope during multiple rainfall events. Effects of varying rainfall characteristics as well as a range of crust and moisture conditions of soil surface as well as soil management (e.g., Wang et al., 2008; Hu et al., 2013a) onto SOC transport should also be investigated.

(4) Can you show the standard deviation of the original soil as well in Figures 3, 4,5? It is difficult to tell otherwise if the observed differences are relevant or not.

Answer: The standard deviation of the original soil will be added in the revised manuscript. Please see the new figures at the end of this file (or the supplement pdf file): In relation to figure 4, if most CO2 comes from the fine fractions (due to their total mass) part of this is at the same time related to the loess soil you are using, which does not reflect global soil diversity (in conflict with your extrapolation to the global scale). At the same time, where is the burial effect taken into account there? SOC mineralization is physically constrained by burial. How could this change your results? Answer: According to Figure 4 and Figure 7, most CO2 emissions (53%) came from the coarse fractions of EQS > 63 μm. This is, on one hand, because of the greater total mass of these coarse fractions (light blue boxes in Figure 2); on the other hand, due to their greater susceptibility to mineralization (light blue boxes in Figure 5). Such observations from a single soil type cannot represent the global soil diversity. However, as a first study aimed at quantifying the potential effects of aggregation onto the movement and fate of eroded SOC, these findings just illustrate the need for further investigation on various soil types.

An enrichment of SOC in terrestrial deposition suggests a reduction of net lateral SOC transfer from eroding sites to depositional sites than estimated in previous reports. This further implies a reduction in all the long-term deposition sites further downslope than the colluvial deposition, and thus a reduced effect of deep burial. Although the significance of such reducing effects remains speculative, the net effects of erosion as a CO2 sink/source requires an investigation of aggregation on current slope-scale carbon balances. Further investigations on other relevant factors (see answer above) are required.

(5) The authors question in a couple of occasions the often reported association of SOC with mineral particles. They show that while 61% of the sediment fractions were in EQS of 32-125 m, containing 65% of SOC. However, the difference between 61% and 65% does not seem enough to support the affirmation that SOC is not associated to mineral particles.

Answer: We did not state that SOC is not associated to mineral particles. We stress that sediment fractions and the associated SOC are moved and transported in form of aggregates, rather than individual mineral particles. The reference to this particular result, "while 61% of the sediment fractions were in EQS of 32-125 μm, containing 65% of SOC", is not intended to compare the differences between 61 and 65%, but to illustrate the contrast of aggregate specific SOC distribution (Figure 2, 3) and the mineral particle specific SOC distribution shown in Table 1. According to the mineral particle distribution, 62% of the particles were < 32 μm carrying about 81% of the total SOC.

(6) Section 4.1 is weak and not supported by any references other than a previous experiment from the same authors. I suggest to either integrate this as part of the results or provide additional discussion and contrast with results from other studies.

Answer: This study is the first using settling tube to fractionate eroded sediment and investigate the transport distance of eroded SOC. So, there are barely other studies to refer to. In order to strengthen our argument, comparison with other fractionation methods using wet sieving, although not strictly comparable, can be added. For instance, the distinct SOC distribution across aggregate size classes is consistent with the field investigation by Polyakov and Lal (2008), where the coarse aggregates (1–0.5 mm) fractionated by wet-sieving, contained up to 4.5 times more SOC than the finest

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fraction (< 0.05 mm).

(7) In page 8832 lines 18-19 explain these “diverse impacts”.

Answer: The qualities and stabilizing mechanisms of SOC in the soil matrix are varying with aggregate conditions (Six et al., 2002). For instance, physically-stabilized SOC within macro- and micro-aggregates is protected by forming physical barriers between microbes and enzymes and their substrates, and thus very susceptible to mineralization after aggregates break-up. Chemically-stabilized SOC results from the chemical or physicochemical binding between SOC and soil minerals (i.e. clay and silt particles). Such stabilization is also likely to be disturbed by aggregates break-up. Biochemically-stabilized SOC is resulted from the inherent or acquired biochemical resistance to decomposition. Aggregates break-up might also affect the biodegradability of the SOC or the exposure to hydrolyzation. Therefore, erosion, either breaking aggregates from soil matrix or out of an aggregate itself, may have distinct impacts on mineralization of eroded SOC.

(8) In relation to the incubation, did you take into account the effect of re-wetting on the CO2 initial pulse?

Answer: The fractionated sediments were re-wetted on previous day before conducting the respiration measurements. In this way, the initial CO2 pulses of rewetted soils should be largely excluded (Orchard and Cook, 1983). Even if there were any CO2 pulses induced by rewetting, this exactly mimics the natural processes, where dry sediments deposited from previous rainfall events, experience a second time of erosion and transport processes. To determine the quality of eroded SOC, it requires monitoring long-term mineralization potential.

Figures:

Figure 3 (Fig 1 automatically filed here) The distribution of soil organic carbon (SOC) (a), and soil organic carbon (SOC) mass (b) in different Equivalent Quartz Size (EQS)

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classes of the sediment. The bold and dashed lines in (a) denote the average and standard deviation of soil organic carbon (SOC) of the original soil. Colors of the boxes correspond to the likely fate of each fraction after erosion. See section 4.1 and Figure 6 for definitions and explanation of the three manners of likely fate. Bars in the boxes represent median values. Whiskers indicate the lowest datum within 1.5 interquartile range of the lower quartile, and the highest datum within 1.5 interquartile range of the upper quartile (n = 18).

Figure 4 (Fig 2 automatically filed here) The distribution of instantaneous respiration rate (a); and potential CO2 emission (b) in different Equivalent Quartz Size (EQS) classes of the sediment. The bold and dashed lines in (a) denote the average and standard deviation of instantaneous respiration rate of the original soil. Colors of the boxes correspond to the likely fate of each fraction after erosion. See section 4.1 and Figure 6 for definitions and explanation of the three manners of likely fate. Bars in boxes represent median values. Whiskers indicate the lowest datum within 1.5 interquartile range of the lower quartile, and the highest datum within 1.5 interquartile range of the upper quartile (n = 18).

Figure 5 (Fig 3 automatically filed here)The distribution of instantaneous respiration rate per gram of soil organic carbon (SOC) in different Equivalent Quartz Size (EQS) classes of the sediment. The bold and dashed lines denote the average and standard deviation of instantaneous respiration rate per gram SOC of the original soil. Colors of the boxes correspond to the likely fate of each fraction after erosion. See section 4.1 and Figure 6 for definitions and explanation of the three manners of likely fate. Bars in boxes represent median values. Whiskers indicate the lowest datum within 1.5 interquartile range of the lower quartile, and the highest datum within 1.5 interquartile range of the upper quartile (n = 18).

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Interactive comment on Biogeosciences Discuss., 11, 8829, 2014.

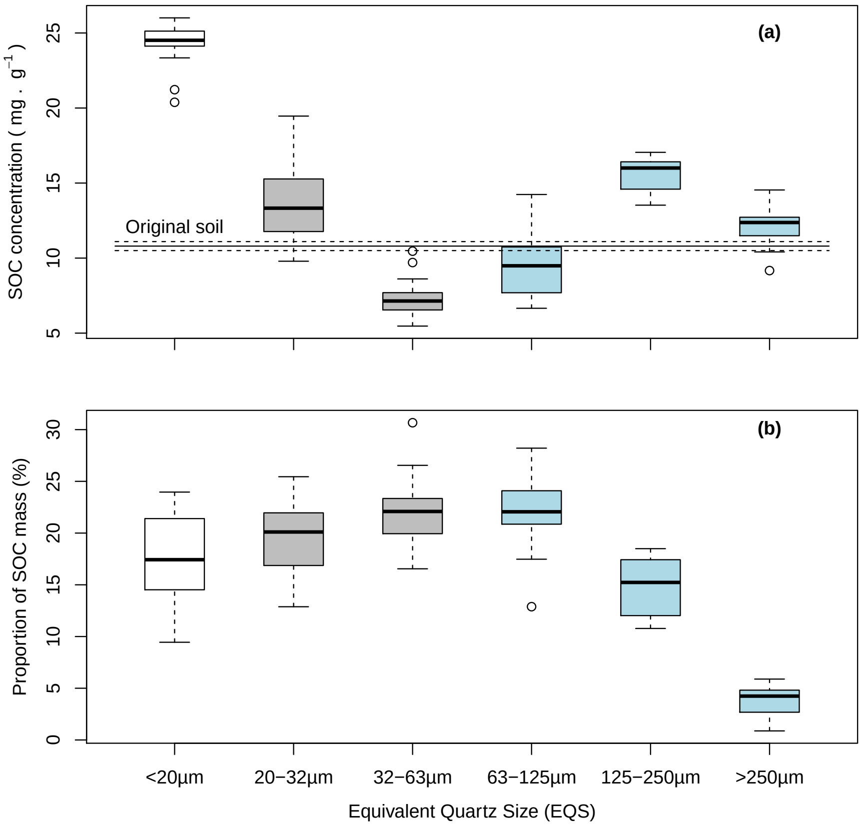
(a)
SOC concentration (mg . g^{-1})
25
20
15
10
5
Original soil
(b)
Proportion of SOC mass (%)
30
25
20
15
10
5
0
<20µm
20−32µm
32−63µm
63−125µm
125−250µm
>250µm
Equivalent Quartz Size (EQS)

Fig. 1.

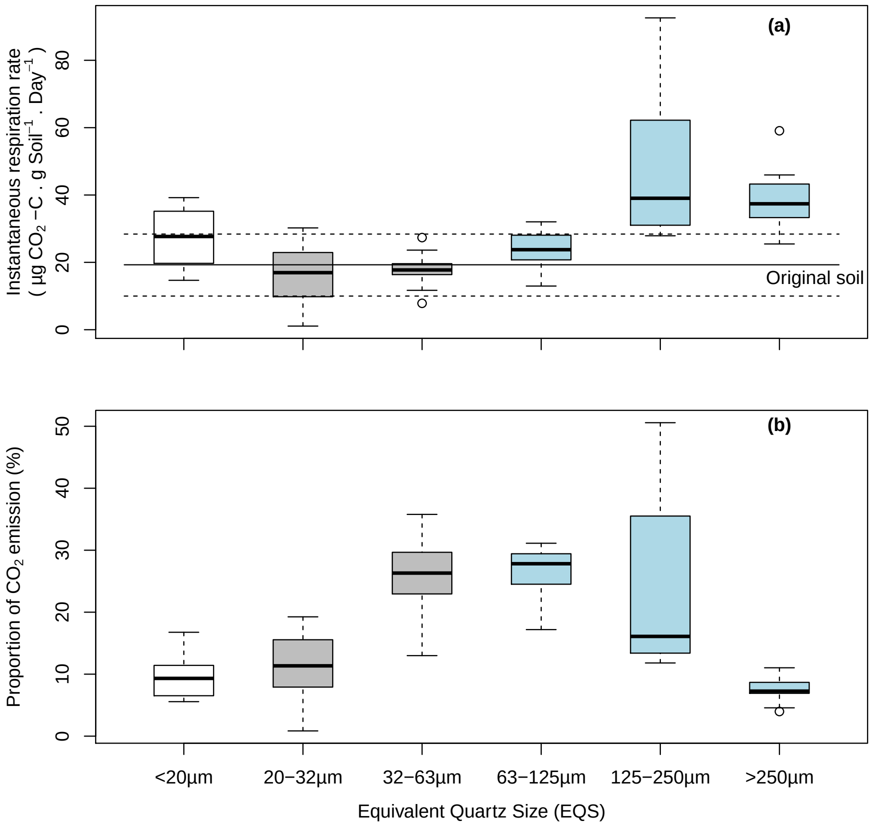
(a)
Instantaneous respiration rate
(µg CO2 −C . g Soil−1 . Day−1)
0
20
40
60
80
Original soil
(b)
Proportion of CO2 emission (%)
0
10
20
30
40
50
<20µm
20−32µm
32−63µm
63−125µm
125−250µm
>250µm
Equivalent Quartz Size (EQS)

Fig. 2.

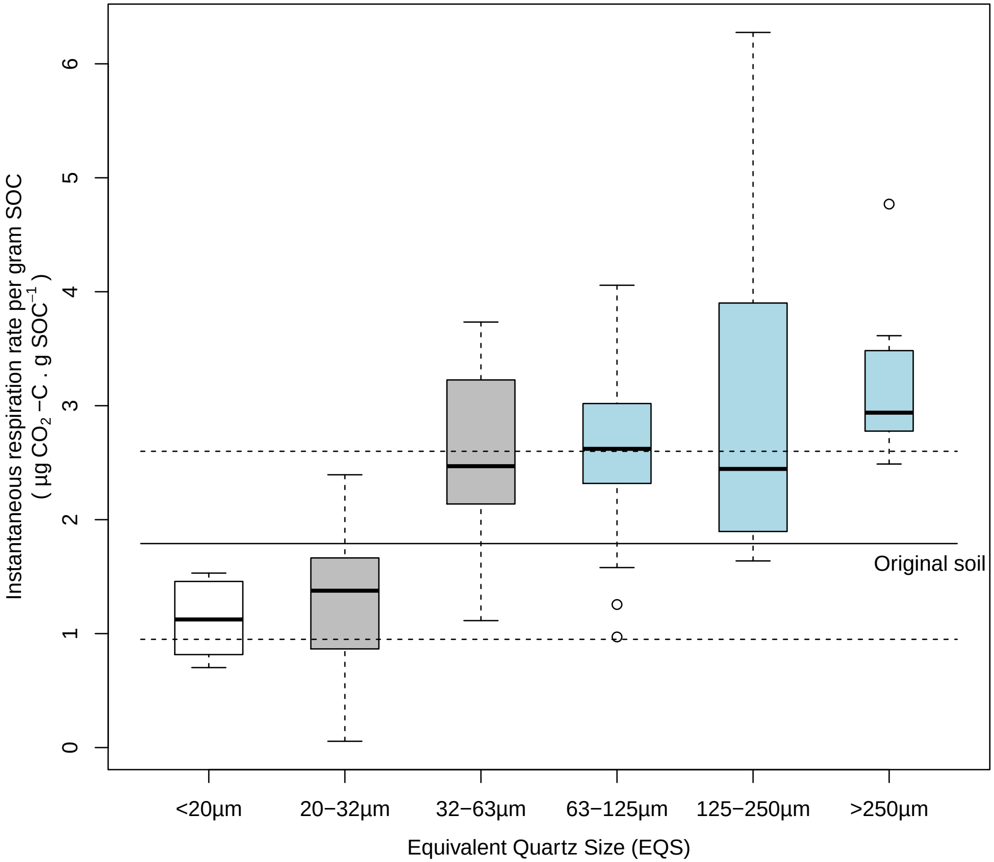

Fig. 3.

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