

Answers to reviewer comments BGD:

We are grateful for the valuable comments, questions and suggestions provided by both anonymous reviewers. They helped us to substantially improve the manuscript. Please find attached the final author comments.

Anonymous Referee #2

The manuscript “Detecting small-scale spatial heterogeneity and temporal dynamics of soil organic carbon (SOC) stocks: a comparison between automatic chamber-derived C budgets and repeated soil inventories” analyses 4 yrs of soil organic C changes by uses of flux chamber technique and repeated soil inventory measurements over a crop field. Data set confirms that AC-based C budgets are suitable to reveal small-scale spatial and short- term temporal dynamics of Δ SOC. The paper is well written and interesting and definitely worth to be published in order to i) show a method comparison and ii) provide evidence on the accuracy of flux vs soil inventory measurement to determine SOC changes over time. I had a number of small remarks I thus recommend (minor) revisions.

General comments:

1. I think authors should not mix terms up being established by the scientific community. Accordingly I recommend to use Δ SOC for the repeated soil sampling and NBP (net biome productivity) NCS (Net C storage) for annual C budgets of chambers (for references see Schulze et al 2007 and Soussana et al 2007, 2010).

A number of different terms have been used by the scientific community to refer to changes in the soil organic carbon stock (Δ SOC). Smith et al. 2010 used the term NECB (net ecosystem carbon budget), which equals NBP (Net biome productivity) when integrated over time. Leifeld et al. 2011 used the term Δ SOC, whereas NCS is e.g. used by Soussana et al. 2010. All of these refer more or less to the same target value (changes in soil organic carbon stock), but vary regarding the way of how to achieve this value (e.g. direct vs. indirect). To reduce confusion within the MS which compares changes in soil organic carbon stocks, we decided to use Δ SOC for both methods (soil resampling as well as chambers), instead of referring to two different terms for the same target value. To better address this, we included the following sentence within the Introduction.

“By contrast, the net ecosystem carbon budget (NECB; Smith et al. 2010) and thereon based temporal dynamics of Δ SOC can be easily derived through the eddy covariance (EC) technique as a common approach to obtain gaseous C exchange (Alberti et al., 2010; Leifeld et al., 2011; Skinner and Dell, 2015).”

2. Before experiment field site received soil, this increased SOC stock and %soilC. To my opinion authors cannot start Δ SOC estimations from that date on as this has nothing to do with the accumulation of C by the ecosystem functioning. I recommend to skip this section in MM and results and estimate Δ SOC as the difference between 2011 and 2014. M&M section.

We regret the misunderstanding and agree that estimating Δ SOC should not start prior to the soil manipulation experiment. As shown in Fig. 1, 3 and 5, estimation of Δ SOC only refers to the period after soil manipulation (2011-2014) for both, chamber derived C budgets and soil resampling based Δ SOC estimates. We decided to keep the year 2010 inside the data set in order to show the important information about the soil manipulation event. However, to better address this really important issue and to avoid misunderstandings, we added the following to paragraph 2.1 of the MS.

“ Δ SOC derived through soil resampling and AC-based C budgets, was compared for the period between April 2011 and December 2014 (Fig. 1).”

3. Beside I got it wrong (L137ff), I found it a bit scary that chambers had no replicate measurements and that authors privileged the topographic gradient. I think this is the most critical point of the study. Accordingly I was wondering how mean \pm SE was estimated for the AC measurements?

We agree that when aiming to detect small-scale spatial heterogeneity, spatial replication is a prerequisite. However, the focus of our study rather was to show, that AC measurements are able to achieve the same resolution in detecting spatial differences as the soil resampling method whilst also handing us information about the critical temporal dynamics that lead to spatial differentiation. The measurement errors of the AC measurements do not include spatial uncertainty but are rather a result of data aggregation and the limited measurement precisions of flux measurements and gap filling. Moreover, soil properties, plant growth and microbial activity might change within a meter, which is exactly the spatial scale we wanted to address. To better express this we changed parts of the introduction, referring to the small-scale spatial heterogeneity and the advantages of the presented chamber based approach (please see answer to comment 1).

4. I was wondering why authors estimated NPP_{shoot} per day and not by uses of degree day which would have been more adapted to physiological biomass evolution and easier to compare between years . This is misleading and has nothing to do with the experiment except some CO₂ exchange from soil which is difficult separate from CO₂ flux.

We estimated NPP_{shoot} per day based on a growth function, which usually predict crop growth as a function of crop age (Zeide 1993). Daily NPP_{shoot} is an essential part of Eq. 4 and needed to derive Δ SOC for AC-measurements. Daily NPP_{shoot} was used to calculate daily Δ SOC values (NEE+NPP_{shoot}= Δ SOC), which were day wise summed and used in Fig. 5 to display the Δ SOC dynamics throughout the study period. Thus, we estimated NPP_{shoot} per day to keep the relation with measured NEE per day. In addition to that, (growing) degree days (GDD) as a measure of cooling or heating are a one-dimensional/mono-causal variable used to predict plant development rates. This is neglecting differences in soil moisture or the influence of heat stress and PAR on plant/biomass development. The one-dimensionality as well as different baseline temperatures for different crops (e.g. 10°C for maize and 5.5°C for wheat) might also hamper a clear comparison between different years.

5. I suggest to set soil inventory Δ SOC as the difference between April 2011 and 2014.

Soil inventory Δ SOC already refers to the difference between 2011 and 2014 within the MS (please see Fig. 1, 3 and 5). To better address this important issue and to avoid misunderstandings, we added the following sentence to the MS.

“ Δ SOC derived through soil resampling and AC-based C budgets, was compared for the period between April 2011 and December 2014 (Fig. 1).”

6. The soil sampling part is a bit unclear, -as the depth of horizons are not clear and do vary with ecosystems – recommend to use cm depths -the mixed soil? here I suggest to skip the 2010 sampling. - missing information on the estimation of soil C stocks. Eg did bulk density vary with depth, location?. Was bulk density normalized (for layers, year) before estimation?

We rewrote and specified the soil sampling paragraph (for more details, please see answers to comment 17, 18 and 19). We decided to keep the year 2010 inside the data set and MS in order to show the important information about soil manipulation. However, if needed, we will remove it.

7. Discussion, I awaited more discussion on the effect of ecosystem on NCS. So to say the crop rotation and why is doing better than the other. Having some data analyses on the effects climate, crop species and duration of bare soil. Soil N content was mention in results but not in discussion.

We agree that the accuracy and precision of presented AC-derived Δ SOC values in general allow for comparisons between different crop rotations, soil types, fertilization treatments and weather conditions. However, since the exemplary field study in our MS (presented to show the accuracy and precision of AC-derived Δ SOC) contains only one crop rotation with different crops during different years, analyses regarding the impact of weather conditions and crop species are difficult. We neither have measurements of the same crop species during different years, nor different crop rotations measured during the same years, since this aspect was not within the scope of our study. However, showing the accuracy and precision of our approach to detect Δ SOC, studies like this can be done in future.

Specific comments

8. L138.... were set up at the depression (Sommer et al., 2016) (see 2.2.1).

We added "(see 2.2.1)" to the sentence.

"During June 2010, four automatic chambers and a WXT520 climate station (Vaisala, Vantaa, Finland) were set up at the depression (Sommer et al. 2016) (see 2.2.1)."

9. L141-143 this is misleading I suggest to remove this section from M&M and results...the soil inventory Δ SOC is thus april 2011 to 2014!!

We agree. This is misleading indeed. Actually we already only compared the period April 2011 to December 2014 (as shown in Fig. 1, 3 and 5). To better address this important issue, we added the period also to the figure caption of Fig. 6. Moreover the following sentence was added to 2.1:

" Δ SOC derived through soil resampling and AC-based C budgets, was compared for the period between April 2011 and December 2014 (Fig. 1)."

10. L185- 187 "An For easy...site" remove this phrases

We removed the sentence from the MS.

11. L191 what about chamber heating?

As stated within section 2.2.2 *"the following exclusion criteria: (i) range of within-chamber air temperature not larger than ± 1.5 K (R_{eco} and NEE fluxes) and a PAR deviation (NEE fluxes only) not larger than ± 20 % of the average"* were used *"to ensure stable environmental conditions within the chamber throughout the measurement;"*. Despite this precaution to extract an almost undisturbed measurement, the big chamber volume (several cubic meters (see 2.2.1)) and the relatively short measurement time during daytime/summer period (5-10 minutes) mostly prevented a heating up of the chamber headspace.

12. L 206 replace Δ SOC AC by NCS

Please see answer to comment 1.

13. L231 "...of CO₂ concentration data as suggested by..."end of the sentence is missing

We removed the fragment "as suggested by" from the sentence, as it was accidentally left from a previous wording.

14. L281 I am not sure that the LAI_C content relation is useful and is of any help in the present manuscript

As explained in the MS, the LAI to C-content relationship is needed to calculate daily changes in C-content of the aboveground biomass (NPPshoot). No biomass samples were taken between two alfalfa cuts. Instead LAI was measured biweekly and correlated with the C-content in harvested

biomass at each cut. These relationships were used to model the C-content development of alfalfa between two cuts.

“For alfalfa in 2013 and 2014, NPP_{shoot} was modeled based on biweekly measurements of LAI because no additional biomass sampling was performed between the multiple cuts per year. To calculate the C content corresponding to the measured LAI, the relationship between LAI prior to the chamber harvest and the C content measured in the chamber harvest of all six alfalfa cuts was used.”

15. L288 Calculation of Net Carbon Storage (NCS)

Please see answer to comment 1.

16. L293ff suggest mention the whole equation as used in literature for NCS (NBP), describing which components were ignored and not.

We agree and are now presenting the entire equation used to calculate NECB and thus ΔSOC .

17. L311 Horizons Ap is difficult to understand and varies between sites and ecosystems, I suggest to use the depth (eg 0-15cm) instead

We agree and rewrote and specified the sentence including made suggestion.

“After soil manipulation, a 5-m raster sampling of topsoils (Ap horizons) was performed during April 2011. Each Ap horizon was separated into an upper (0-15 cm) and lower segment (15-25 cm), which were analyzed separately for bulk density, SOC, Nt and coarse fraction (< 2 mm) (data not shown). From these data, SOC and Nt mass densities were calculated separately for each segment and finally summed up for the entire Ap-horizon (0-25 cm). The mean SOC and Nt content for the Ap horizon of each raster point was calculated by dividing SOC or Nt mass densities (0-25 cm) through the fine-earth mass (0-25 cm). In December 2014, composite soil samples of the Ap horizon were collected. Composite samples consist of samples from four sampling points in a close proximity around each chamber.”

18. L313 soil cores need more details on diameter, depth...

We changed “cores” into “samples” and added details about how these samples were taken (please see answer to comment above)

19. L313....In December 2014, mixed soil samples were collected from the Ap horizon next to each chamber...What are mixed soil samples?

Mixed soil samples refer to a composite sample, which consist of several samples taken in close proximity to a chamber. These samples were mixed prior to analysis. To better address this, we rewrote the sentence.

“In December 2014, composite soil samples of the Ap horizon were collected. Composite samples consist of samples from four sampling points in a close proximity around each chamber. “

20. L348 “NPP shoot between chamber positions and....” - not clear what means positions

Chamber position simply refers to the different chambers and their position within the landscape (along a small-scale gradient/transect). To better address this, we deleted the word “positions” from the sentence.

“Again, lower differences in annual NPP_{shoot} between the chambers and no spatial trends were found for alfalfa in 2013 and 2014.”

21. L368” As a result of soil translocation in 2010, initially m....” delete

Please see answer to comment 9.

22. L379 “Average annual Δ SOC values for the soil resampling and C budget method are shown in Fig. 6.” Difficult to see from Fig 6 suggest to add the numbers in table 1 .

We agree and added the average annual Δ SOC values to Tab.1 as suggested.

23. L391 soils (Conant et al., 2010; Xiong et al., 2016). Delete citation as not its place here

We delete the reference from the sentence as suggested.

24. L488 “We confirmed that AC-based C budgets are able to reveal small-scale spatial and short-term” not sure this is true with 4 chambers only

We added results of the Wilcoxon rank sum test (regarding spatial differences of monthly aggregated NEE, NPP and Δ SOC values) to Tab. 1. Please see also answer to comment 3. In addition we changed the sentence as follows:

“We confirmed that AC-based C budgets are in principle able to detect small-scale spatial differences and might be thus used to detect spatial heterogeneity of Δ SOC similar to the soil resampling method. However, compared to soil resampling AC-based C budgets also reveal short-term temporal dynamics”

25. Table 1 : Suggest to add a column Δ SOC values (2011-2014) for soil resampling and cumulated C budget (2011-2014). Would be nice to have the crop rotation in the 1st column. What about standard deviation for soil sampling?

We agree and added Δ SOC values for soil resampling (difference between 2011 and 2014) as well as average annual Δ SOC values for both methods to Tab. 1. Crop rotation was implemented in Tab. 1 as suggested. No SD can be given for composite samples. Instead a CV (<10%) of laboratory analyses repetitions is given.