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Interactive comment on "On the rebound: soil organic carbon stocks can bounce back to near forest levels when agroforests replace agriculture in southern India" *by* H. C. Hombegowda et al.

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RESPONSE TO REFEREE 2:

General comments

Referee: This study reports an interesting and unique data set on land use and management changes from forest to agriculture to agro-forestry systems in India. There are few studies on soil carbon (SOC) dynamics after land use transitions from India and also few studies from agro-forestry systems (AFS), covering different AFSs making the study very valuable. The study is written and structured very clear and professional.

However, there is one major concern that needs to be considered in order to get this paper in a publishable status. Also some minor remarks maybe considered to improve the paper.

Authors: We would like to thank the reviewer for his or her thorough evaluation of the manuscript. As a result we have made numerous changes in the manuscript to address the issues he/she has raised.

Major remark

Authors: The response for this major remark will be addressed in three parts.

Referee: The depth distribution of SOC stock changes is a critical issue (Fig. 3) since you found minor differences in relative and absolute SOC stocks changes throughout the soil profile. This aspect required more explanations (p. 9, l. 25 f) and more attention.

Authors: We would argue that differences were not minor. Doubling of soil carbon is not minor.

Within a time period of several decades land use changes should generally affect top soils more than subsoils since most carbon input occurs close to the soil surface from litter and roots. Poeplau and Don, 2013 Geoderma, e.g., found only 10% of the SOC stocks changes in 30-80 cm depth, also for afforestation with similar age and likely also similar rooting distribution as in AFSs. About 90% of the changes occurred in the topsoil (0-30 cm depth). This is also reported in many other studies (e.g. Degryze et al. 2004, GCB) on land use change effects.

Authors: We think the reviewers may have misinterpreted the meaning of the depth profile figure (Figure 3). This depth profile shows the percentage change in soil carbon for each respective depth and not in relation to the full soil profile. For instance, if there is a 100% increase at 60-100cm it simply means that at that depth the SOC stock doubled.

Nevertheless, the reviewer is partly correct in that the changes are most intense at the soil surface. This is evident if we look at the magnitude of SOC stock changes normalized for 10cm increments throughout the soil profile (see grey bar in Fig. 1). This shows that between 17-32% of the soil profile SOC changes took place in the top 10 cm. However, when we consider the whole soil profile (which has a much bigger volume), there are very large carbon gains below 30cm. In homegardens 58% of the gains occurred below 30cm, for coffee 26%, for coconut 59%, and for mango 50%. In Fig. 3, we have now added the corresponding carbon change in percent of the overall change in the soil profile. We opted not to show the normalized values (as in Figure 1) as we thought it would confuse the reader. In the text, we have provided more detail on where in the soil profile the SOC changes are occurring in terms of the overall change (see page 9, line 17-18).

In contrast to the papers the reviewer cites, which are all in the temperate zones, we found a few a papers in the tropics which showed similar trends as ours (Saha et al, 2010; Hooker and Compton, 2003). Most notably is the paper by Saha et al 2010, who also investigated soil carbon in Indian AFS (coconut, homegardens, and rubber). In comparison to upland rainfed rice paddy fields (not flooded) most carbon differences in the AFS were in the subsoil (here below 20cm). For coconut there was only a 3% gain in at the soil surface and for the homegarden (HGL and HGS) only 7% combined (interpreted from Fig. 2 and values shown in the Table beside it).

We believe the carbon gains at depth are a result of a number of processes: 1. The deep rooting profile of the AFSs means that organic matter inputs are injected into the subsoil. Coconut trees, for instance, have very fibrous and profuse root systems. This is in clear contrast to agriculture where annual crops have shallow rooting systems and are tilled frequently. 2. The high intensity precipitation (monsoon rains) in the humid and sub-humid regions leads to higher water infiltration and result in a high mobilization of DOC (Rumpel and Kögel-Knabner, 2011; Follett, et al., 2009). 3. Collection of coconut leaves for domestic use (thatching, cooking) means there is little organic

matter input at the soil surface – for this AFS. 4. Time. Most of these AFS are quite old (ranging in age from 45 to 85 years) and accordingly there has been sufficient time for SOC stocks to accumulate at depth.

The simplest explanation of uniform SOC differences throughout the soil profile are differences in the soil type or soil texture that put the soils to different SOC levels. Thus, differences between land use systems may thus be a result of soil intrinsic variables and can thus not be attributed to land use. If the assumption that the small systematic differences in clay content between the paired sited had no effect on the results (Chapter 3.1) should be checked using SOC loads per %clay from the literature (e.g. Leifeld and Kogel-Knabner, 2005, Geoderma) or using the own model that contains clay a predictor variable (see also comment of referee #1 on this contradiction that need to be solved). Further work is required to disentangle clay content effects from land use effects.

Authors: On the reviewer's advice we explored the implication the clay differences have on SOC stocks. Specifically, we calculated a SOC correction factor that would remove the effects of the clay differences – on the assumption there was really an intrinsic difference in the soils. The correction factor was calculated using the relationship clay has with soil organic carbon (at each individual depth, in undisturbed systems) and then this correction constant was added to the SOC stock at the converted land-uses (agriculture or AFS). For instance, for agriculture where there was on average 5.5% less clay than the forest, we recalculated the new SOC stock of the agriculture by adding the theoretical amount of C stored that would have been stored by higher clay content. For the AFS systems there was 3.2% less clay than the forest (an increase of 2.2% from the agriculture). Accordingly, to correct for the clay difference, the carbon contents increased in these converted systems (compare red and black dots in Fig. 3).

If we look at the changes in the depth profile for the conversion of agriculture to AFS we observe a decrease in the percentage change (compare red and greyscale dots in the Figure below) – as the reviewer had hinted at. This change however simply reflects that there was a larger correction factor made to the agriculture (5.5% clay difference) than to the AFS systems (3.2% clay difference).

Basically, this clay correction exercise has shown that the story of the paper does not change. It simply shifts the absolute SOC stocks of both agriculture and AFS slightly higher (Fig. 3). While there may appear to be big decreases in the relative changes (Fig. 4), this simply reflects that SOC in the agriculture increased more (higher clay correction factor; 5.5% diff. in clay) than the AFS (lower clay correction factor; 2.3% diff. in clay).

Ultimately however we do not believe that there was an intrinsic difference between the soils of the plot pairs. During the fieldwork we implemented rigorous site selection criteria to find comparable plot-pairs within each cluster. Our site selection criteria included: - Soil texture: (perhaps most importantly) we compared soil textures at different depths (well into the sub-soil) of prospective sites using the feel test. First, we used an auger to collect soil samples from prospective sites and later once the soil samples were collected, we carefully compared soil textures and based on texture differences either accepted or rejected sites for this study. While the feel test method may not yield quantitative values of grain sizes, it is more than sufficient to compare whether soils are similar or not. - Distance between plot pairs: we looked for sites located in close proximity of another, with all of the plots within a cluster located within a maximum of 1-km distance of each other. Keeping the plots as close as possible should minimize pedological differences in the soil types. - Topography: we chose sites on similar landscape positions with similar slopes. This was not difficult however since most of the sampling region has only light undulating hills with homogeneous soils. This is reflected in the plot slopes which were on average 3% and maximally 7% (measured with a clinometer).

In contrast to other regions of the world where remnant intact forests are difficult to find and are generally located on poor agriculture soils, the forest we used in this study were originally selected because of their religious significance. These so-called

“sacred groves” were almost always located centrally, surrounded by agriculture and agroforestry systems.

As we already explained above (reviewer #1), we believe that the (small) clay differences are a result of erosional processes taking place at the soil surface over a period of decades. This has also been observed in other studies (Gonzalez and Laird, 2003). The loss of clay particles through erosion losses has now been included in the text (see page 12, lines 12-18) as a potential mechanism for the carbon loses.

Minor remarks Referee: 1. Is there any renewing of AFS? For mango, e.g., it was reported that farmers use the establishment phase differently that the later stages of the plantation (p. 5, l. 15). Is AFS permanent? Is it reconverted to cropland or are trees cut at some time as part of a AFSs renovation process which possibly would effects SOC?

Authors: The AFS are permanent. Nevertheless, there is a constant renewal of trees within the AFS but only insofar that dead and diseased trees are removed and replaced with young trees. Considering that this is a gradual process taking place over the duration of the AFS lifespan, there should not be any abrupt effects on SOC.

Referee: 2. Provide the diameter of the probe (p. 6, l. 2) and the number of replicates of bulk density sampling (p. 6, l.5).

Authors: The core was 5.3 cm in diameter and 7.5 cm in height, which equals 165 cm3. Two replications samples were taken at each measurement depth. This information was added to the text (page 7, line 13-16).

Referee: 3. Mention if any carbonate/inorganic carbon was present in the soils or if soil carbon is equal to soil organic carbon in this study.

Authors: There were no carbonates in the soils in our study region. All the plots were located on the Indian Shield which consists of rocks formed during the Precambrian (Archean and Proterozoic Eons). These rocks consist of gneisses, charnockites (high grade metamorphic rocks) and granites and are all devoid of carbonates. We added this in the text (page 7, line 18-20).

Referee: 4. What is difference between mass correction (after Ellert and Bettany 1995) and the method you applied with using the forest bulk density for all treatments? (p. 6, l. 12 f). For cropland conversion to AFS the land use system with the lowest bulk density (either cropland or AFS) should be used for a mass correction, not the bulk density of the forest that is not part of this comparison.

Authors: The discussion of how to deal with bulk density changes caused by land-use change in the SOC calculation has featured in numerous papers (for example: de Blécourt et al. 2013; de Koning et al 2003; Mekuria et al. 2011; Powers et al. 2011; Veldkamp 1994). Changes in bulk density (caused by land-use change) can have a profound influence on SOC stock comparisons and accordingly needs to be addressed to achieve accurate estimates. The approach we use here (using bulk density estimates from the forest reference plot) is a method introduced by Veldkamp (1994) and has been widely used. Essentially, Veldkamp (1994) determined that it is the same whether one uses the bulk density of the reference land use or uses fixed soil mass by adjusting the soil depth in the converted land use.

We used the bulk density of the forest reference to standardize all our SOC stock calculations to the same reference. With this approach our change estimations from agriculture to AFS will be on the conservative side. Had we used the bulk density of the agriculture for our AFS SOC calculations, our stocks would have been substantially higher and accordingly also the gains. Lastly, the measured bulk densities of the AFSs (1.08±0.01 g cm-3) were just slightly higher than the forest (1.06±0.01 g cm-3) reference.

Referee: 5. Chapter 3.1 should become part of the material and methods section in order to start the results section not with methodological assumptions.

Authors: On the reviewer's advice, we have now incorporated this information into ma-

terial and methods section. In moving it we have tried to maintain the same message. (page 5, line 8 to 19).

Referee: 6. P. 8 l. 13ff: Did you include any variable for the litter input in the analysis? You mentioned that at some AFS litter was extracted at some not. I propose to estimate whether liter extraction had an effect on SOC stocks in the regression analysis directly by using an estimate for the litter input (not only via basal area) – if available.

Authors: Unfortunately, we could not measure nor could we find any data on litter inputs into these different systems. There is simply too little research done on this in this region.

Referee: 7. Please provide a reference that aluminum toxicity plays a role also for pH 4.5, which was the lowest pH in your study. I assume that you need lower pH for toxic effects of aluminum.

Authors: The reviewer is correct. Aluminum toxicity starts at a pH of approximately 5. Accordingly, we have removed aluminum toxicity as a possible explanation. We have now generalized this explanation to reflect that decomposition processes at either end of the pH scale (acidic or basic) are retarded when the biochemical environment is sub-optimal (page 11, line 8-13).

Referee: 8. P. 10. L. 5: How does mineralogy affect SOC at high pH? Rephrase this sentence in order to mention the process/mineral to which this affect is attributed.

Authors: In our original manuscript the justification for the higher SOC stocks at higher pHs was based on the explanation given by van Noordwijk et al. (1997). In his study he observed a similar relationship and attributed the phenomenon to clay minerology. However, on closer inspection of the paper we discovered that they do not provide any evidence - or even a citation - as to how they reached this conclusion. We have now rewritten this section to reflect that decomposition processes at either end of the pH scale (acidic or basic) are retarded when the biochemical environment is sub-optimal (page 11, line 8-13).

Referee: 9. P. 10. L. 30: How does clay mineralogy affect SOC changes? Rephrase this sentence in order to mention in which way clay mineralogy affect SOC changes according to Powers et al..

Authors: We have rephrased this sentence.

Referee: Fig 2 and 3: Indicate significant differences with different letters.

Authors: We added the letters for Figure 2, but not for Figure 3. We opted not to include them for Figure 3 because we felt it was not a legitimate comparison to examine the relative SOC changes (in percent) between AFS types, as this does not reflect the actual magnitude of change.

Referee: Fig 2: Explain in figure caption if you display absolute or relative changes. The arrows are not clear, since they are not clear enough connected to either humid or dry sub-humid data. Two separate arrows are maybe better or no one.

Authors: The graphs show the absolute SOC stocks – not changes. We have changed the figure caption to make this clear. We have also removed the arrows and the associated numbers because it was not clear what they meant.

âĂČ Reference list: De Blécourt, M., Brumme, R., Xu, J., Corre, M. D. and Veldkamp, E.: Soil Carbon Stocks Decrease following Conversion of Secondary Forests to Rubber (Hevea brasiliensis) Plantations, edited by B. Bond-Lamberty, PLoS ONE, 8(7), e69357, doi:10.1371/journal.pone.0069357, 2013. De Koning, G. H. J., Veldkamp, E. and LópezâĂŘUlloa, M.: Quantification of carbon sequestration in soils following pasture to forest conversion in northwestern Ecuador. Global Biogeochemical Cycles, 17(4), 2003. Dourte, D., Shukla, S., Singh, P. and Haman, D.: Rainfall intensity-duration frequency relationships for Andhra Pradesh, India: changing rainfall patterns and implications for runoff and groundwater recharge, Journal of Hydrologic Engineering, 18(3), 324-330, 2012. Follett, R. F.O, Kimble, J. M., Pruessner, E. G., Samson-Liebig, S.

and Waltman, S.: Soil organic carbon stocks with depth and land use at various U.S. sites. Soil carbon sequestration and the greenhous effect, 2nd edn. SSSA special Publication 57, Madison, pp 29–46, 2009. Gonzalez, J. M. and Laird, D. A.: Carbon Sequestration in Clay Mineral Fractions from C-Labeled Plant Residues, Soil Science Society of America Journal, 67(6), 1715-1720, Mekuria, W., Veldkamp, E., Corre, M. D. and Haile, M.: Restoration of ecosystem carbon stocks following exclosure establishment in communal grazing lands in Tigray, Ethiopia. Soil Science Society of America Journal, 75(1), 246-256, 2011. Pietri, J. A. and Brookes, P. C.: Substrate inputs and pH as factors controlling microbial biomass, activity and community structure in an arable soil, Soil Biology and Biochemistry, 41(7), 1396-1405, 2009. Piña, R. G. and Cervantes, C.: Microbial interactions with aluminium, Biometals, 9(3), 311-316, 1996. Poeplau, C. and Don, A.: Sensitivity of soil organic carbon stocks and fractions to different land-use changes across Europe, Geoderma, 192, 189-201, 2013. Powers, J. S., Corre, M. D., Twine, T. E. and Veldkamp, E.: Geographic bias of field observations of soil carbon stocks with tropical land-use changes precludes spatial extrapolation, Proc. Natl. Acad. Sci., 108(15), 6318–6322, doi:10.1073/pnas.1016774108, 2011. Rezaie, N., Roozitalab, M. H. and Ramezanpour, H.: Effect of land use change on soil properties and clay mineralogy of forest soils developed in the Caspian Sea region of Iran, Journal of Agricultural Science and Technology, 14, 1617-1624, 2012. Rumpel, C. and Kögel-Knabner, I.: Deep soil organic matterâĂŤa key but poorly understood component of terrestrial C cycle, Plant and Soil, 338(1-2), 143-158, 2011. Saha, S. K., Nair, P. R., Nair, V. D. and Kumar, B. M.: Carbon storage in relation to soil size-fractions under tropical tree-based land-use systems, Plant and soil, 328(1-2), 433-446, 2010. Van Noordwijk, M., Cerri, C., Woomer, P. L., Nugroho, K. and Bernoux, M.: Soil carbon dynamics in the humid tropical forest zone, Geoderma, 79(1), 187–225, 1997. Veldkamp, E.: Organic carbon turnover in three tropical soils under pasture after deforestation, Soil Sci. Soc. Am. J., 58(1), 175–180, 1994.

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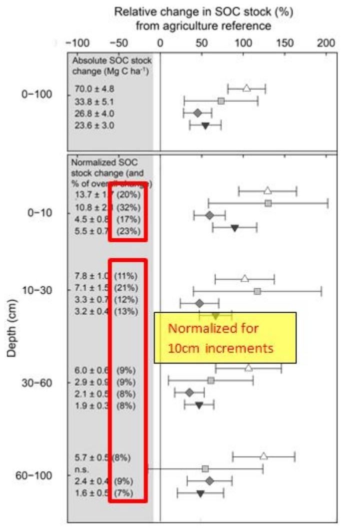
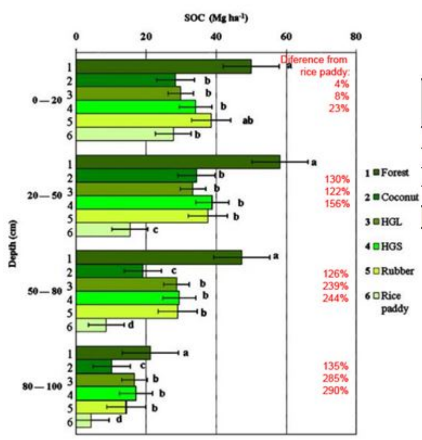


Figure 1: Here we demonstrate normalized SOC changes for 10cm depth increments in the 1-m profile. It shows that the strongest SOC changes occur at the soil surface (number in red box).
This is a modification of Figure 3 in the manuscript. Changes in SOC stock in the 1-m soil profile from agriculture to agroforestry systems (homegarden (△; n=27), coffee (□; n=9) coconut (◆; n=28) and mango (▼; n=28).

Fig. 1. Fig 1



Difference in SOC stock between the original land use - rice paddy and the AFS (Mg C ha-1). The percentage value in brackets indicates where in the profile differences occur (%)

Depth (cm)	Coconut	Home garden large (HGL)	Home garden small (HGS)
0-20 cm	1.1 (3%)	2.2 (4%)	11.1 (10%)
20-50 cm	19.6 (53%)	18.3 (35%)	22.2 (37%)
50-80 cm	10.7 (29%)	20.2 (38%)	20.4 (33%)
80-100 cm	5.9 (16%)	12.4 (23%)	12.6 (20%)
Total:	37.2 (100%)	53.1 (100%)	63.3% (100%)

Figure 2: A figure copied from Saha et al. 2010 demonstrating SOC stocks at different depths in the soil profile

Fig. 2. Fig 2

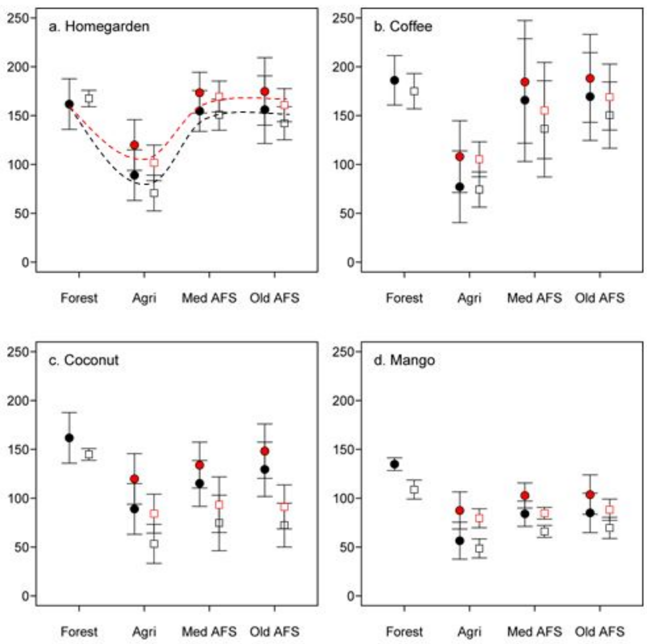


Figure 3: The red dots show the "clay corrected" values. The black are from the original manuscript. For the Homegarden graph we have added a line to demonstrate the SOC stock trend with time. For axis labels and a legend please refer to the original figure (in the manuscript Figure 2)

Fig. 3. Fig 3

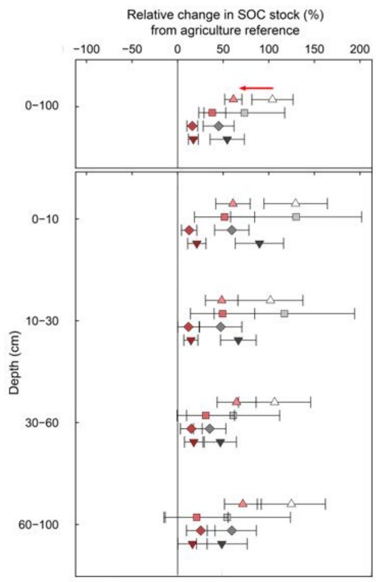


Figure 4: The red dots show the "clay corrected" values.
This is based on the assumption there were intrinsic difference in the soils.
Legend: homegarden (△; n=27), coffee (□; n=9), coconut (◆; n=28) and mango (▼; n=28).
This is a version of Figure 3 in the manuscript.

Fig. 4. Fig 4