

Response to all comments

As pointed out by all reviewers, it is nice to see that a lively debate about the correct calculation of SOC stock is underway. The reviewers and authors have pointed out some valid points, but despite the suggestion that the debate be closed (Referees 1 and 2), there remain a few points of clarification.

Firstly we wish to note that we did not state that the volumetric proportion is incorrect (Poeplau response), but that its use is incorrect.

Secondly, when we approached the authors in June 2017 to suggest we prepare a publication on their paper, as suggested by Referee 2, they stated that they did not think it was necessary.

Chiefly, Poeplau et al. state in their paper that M4, which they use as the 'correct' standard for comparing, is 'the closest approximation to reality'. They also state in their response that M4 with equation 6 is the same as the IPCC standard. Although we are not sure which specific equation is referred to, we ask ourselves why then did they not use it as their gold standard for comparison?

Unfortunately, we were unable to easily identify the referred to IPCC standard. The IPCC equation to calculate the change in SOC stocks available at https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_14_An2_SumEqua.pdf, but it does not deal with initial stock calculations, bulk density or rock fragments. The ISO standard equation for calculating SOC stocks is shown in Bispo et al. (2017) and Cotching et al. (2013), and this was the standard used for the Australian Soil Carbon Research Program (SCaRP, Baldock et al. 2013). It can be shown that M4 and that used in the SCaRP program yield mathematically equivalent results. M4 is however, not statistically equivalent to the derived (IPCC) equation (viii) in our comment, which is illustrated by comparing the errors of the two methods:

The squared relative error of equation (viii) derived in our comment is:

$$\frac{\sigma_{C_{stock}}^2}{C_{stock}^2} = \frac{\sigma_{C_{content,fine}}^2}{C_{content,fine}^2} + \frac{\sigma_{Mass\ proportion_{Rock}}^2}{Mass\ proportion_{Rock}^2} + \frac{\sigma_{\rho_{Sample}}^2}{\rho_{Sample}^2} + \frac{\sigma_{Depth}^2}{Depth^2}$$

With $Mass\ proportion_{Rock} = \frac{Mass_{Rock}}{Mass_{Sample}}$ and $\rho_{Sample} = \frac{Mass_{Sample}}{Volume_{Sample}}$ we obtain:

$$\frac{\sigma_{C_{stock}}^2}{C_{stock}^2} = \frac{\sigma_{C_{content,fine}}^2}{C_{content,fine}^2} + \frac{\sigma_{Mass_{Rock}}^2}{Mass_{Rock}^2} + 2 \frac{\sigma_{Mass_{Sample}}^2}{Mass_{Sample}^2} + \frac{\sigma_{Volume_{Sample}}^2}{Volume_{Sample}^2} + \frac{\sigma_{Depth}^2}{Depth^2}$$

The error of M4 in Poeplau et al. is:

$$\frac{\sigma_{C_{stock}}^2}{C_{stock}^2} = \frac{\sigma_{C_{content,fine}}^2}{C_{content,fine}^2} + \frac{\sigma_{Volume\ proportion_{Rock}}^2}{Volume\ proportion_{Rock}^2} + \frac{\sigma_{\rho_{fine}}^2}{\rho_{fine}^2} + \frac{\sigma_{Depth}^2}{Depth^2}$$

Using the equation 3 in Poeplau et al. for ρ_{fine} and with $Volume\ proportion_{Rock} = \frac{Volume_{Rock}}{Volume_{Sample}}$

we obtain:

$$\begin{aligned} &= \frac{\sigma_{C_{content,fine}}^2}{C_{content,fine}^2} + \frac{\sigma_{Volume_{Rock}}^2}{Volume_{Rock}^2} + \frac{\sigma_{Volume_{Sample}}^2}{Volume_{Sample}^2} + \frac{\sigma_{Mass_{Sample}}^2}{Mass_{Sample}^2} + \frac{\sigma_{Volume_{Sample}}^2}{Volume_{Sample}^2} \\ &\quad + 2 \frac{\sigma_{Mass_{Rock}}^2}{Mass_{Rock}^2} + \frac{\sigma_{\rho_{Rock}}^2}{\rho_{Rock}^2} + \frac{\sigma_{Depth}^2}{Depth^2} \end{aligned}$$

With $\rho_{Rock} = \frac{Mass_{Rock}}{Volume_{Rock}}$ the squared relative error of M4 in Poeplau et al. is therefore:

$$\frac{\sigma_{C_{content,fine}}^2}{C_{content,fine}^2} + 2 \frac{\sigma_{Volume_{Rock}}^2}{Volume_{Rock}^2} + 2 \frac{\sigma_{Volume_{Sample}}^2}{Volume_{Sample}^2} + \frac{\sigma_{Mass_{Sample}}^2}{Mass_{Sample}^2} + 3 \frac{\sigma_{Mass_{Rock}}^2}{Mass_{Rock}^2} + \frac{\sigma_{Depth}^2}{Depth^2}$$

The equation M4 of Poeplau et al. therefore has more sources of error than equation (viii) in our comment. M4 is therefore statistically inferior and should be avoided. This is in line with applying the law of parsimony (Occam's razor) to the problem of SOC stock calculations, which states that when presented with competing answers to a problem, one should choose the one which makes the fewest assumptions. This is important, because as author's we have received reviewers comments criticising the use of the statistically superior equation (viii) whilst advocating the use of the statistically inferior M4. We hope that this proof now serves as an adequate rebuttal of any such

future comments once and for all. As pointed out by the current reviewers, there are numerous sources of error in SOC stock calculations, including one's which have not been considered here, and we as scientists must always aim to minimize or eliminate them.

A quick conversion of the FSS values and Equations 7 and 8 in Poeplau et al. can be readily shown to be equivalent to the standard equation in Bispo et al. (2017) and Cotching et al. (2013), so one wonders if it is such a revelation. While equation 9 of Poeplau et al., which was also introduced in equation 4 of Wendt and Hauser (2013), has the least theoretical error, the practical error associated with sampling to a specific depth remains, so that's its simplicity is partially deceptive. The authors are indeed correct in their assertion that this can be used for multiple depth samples, but they have not clarified the units to be used and this has left some confusion. Presumably the numerator is intended to be measured in g? While Equation 9 from Poeplau et al. is a seemingly attractive option, care must be taken that the calculation of the fine soil stock is not derived from the equations presented in their M4 due to the statistical inferiority of this method.

Of key concern - and not addressed here - is the calculation of SOC stocks in stony soils, as here an accurate estimation of rock content is highly difficult. Estimating rock content from the profile face is highly error prone, because 2D surface areas are not representative of irregular 3D structures, such as rocks. Therefore, estimating rock content from the profile face is not volumetric. Taking larger volumes of sample in very large cores to determine the bulk density of the whole soil would help to alleviate this issue, but would be associated with more field and laboratory work. A systematic study into this issue, similar to the systematic evaluation of sources of error when up-scaling to SOC analyses to landscape stocks (Goidts, van Wesemael & Crucifix, *Europ. J. Soil Science*, 2009, doi: 10.1111/j.1365-2389.2009.01157.x) could help to resolve the issue.

References:

- Baldock, J, McDonald, L and Sanderman, J. (2013). Forward: Special Issue : Soil carbon in Australia's Agricultural lands. *Soil Research* 51, (i).
- Bispo, A et al. (2017). Accounting for carbon stocks in soils and measuring GHGs emission fluxes from soils: Do we have necessary standards? *Frontiers in Environmental Science* 5, 41

Cotching, WE, Oliver, G, Downie, M, Corkrey, R and Doyle, RB. (2013). Land use and management influences on surface organic carbon in Tasmania. *Soil Research* 51, 615 – 630.

Wendt JW, Hauser S (2013) An equivalent soil mass procedure for monitoring soil organic carbon in multiple soil layers. *European Journal of Soil Science* 64(1): 58-65