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# Reply to: Soils need to be considered when assessing the impacts of land-use change on carbon sequestration

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REPLYING TO S. Duarte-Guardia et al. *Nature Ecology & Evolution* https://doi.org/10.1038/s41559-019-1026-8 (2019)

In their comment on our recent study[1], Duarte-Guardia et al.[2] argue that if we had included soil organic carbon (SOC), "a completely different set of conclusions and policy recommendations would have emerged". While we agree with the vast importance of SOC for the global carbon cycle, we do not agree with this statement. We use this opportunity to clarify a few points concerning our study and to speculate about how the inclusion of SOC might have changed our results.

It is important to note that the reason forestry appears first in the ranking is also due to the sector classification of EXIOBASE[3], the economic model used in the study. When we aggregate the sectors used in our study to broad land-use categories (cropping, livestock grazing, forestry), we see that forestry ranks third in terms of overall impacts, albeit with a substantial contribution (Table 1, row 1). By looking at per-area values for lands converted from natural forests, the only conversion considered in our study[1], one can see that the impacts in terms of carbon sequestration per area of converted land are much higher for cropland and grazing land than for forestry (Table 1, row 3).

When conducting our study, we were not aware of any datasets that would have allowed us to assess the impact of land use on SOC with a robustness comparable to our assessment for biomass. Including the impact of different land-use sectors on SOC would require, above all, a map of potential soil carbon stocks, depicting the amount of carbon stored in ecosystems assuming the absence of land use[4.] Such a map of potential carbon stocks serves as reference point for our calculation. In addition, maps that consistently link present SOC patterns to the land-use sectors differentiated in our study do not exist. Finally, the impact of individual land uses on SOC is subject to much larger uncertainties than their impacts on biomass[5,6].

Still, the references Duarte-Guardia et al.[2] cite provide a valuable starting point to address the research frontier of including SOC in such analyses and thereby getting a fuller picture of how land use alters carbon storage at the global level. For instance, Deng et al.[7] summarized 103 plot-level studies on the effect of land-use conversion on SOC (Table 1, row 4). The low number and geographical bias in these plot-level data restrict their use for global wall-to-wall maps as used for biomass in our study. However, their results allow for a very simple back-of-the-envelope calculation to explore how our

**Table 1 | The effect of land use on carbon stocks (with and without considering SOC) on carbon storage**

| | Cropping | Livestock grazing | Forestry |
|---|---|---|---|
| Carbon sequestration lost without SOC – total[a] ($10^6$ tons) | 1,423.4 | 904.1 | 856.0 |
| Converted land area potentially carrying natural forests[a] ($10^6$ km²) | 6.8 | 5.0 | 22.3 |
| Carbon sequestration lost without SOC per area[a] ($g\,m^{-2}\,yr^{-1}$) | 210.1 | 180.1 | 38.5 |
| Emissions from SOC due to conversion from forest[b] ($g\,m^{-2}\,yr^{-1}$) | 174.0 | −68.0 | 63.0 |
| Carbon sequestration lost including SOC[c] ($10^6$ tons) | 2,601.9 | 562.7 | 2255.0 |

[a]Data from ref. 1. [b]Data from ref. 7. [c]Data from combining data from refs. 1,7. Values in row 3 are the result of dividing values in line 1 by those in line 2. Values in row 5 are the result of adding values in line 3 with those in line 4 and multiplying the sum with values in line 2.

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original results might change with the inclusion of SOC. This rough assessment shows that the sector for which the omission of SOC makes the largest difference is livestock grazing, where, according to Deng et al.[7], forest-to-grassland conversion leads to a build-up of SOC (Table 1, row 4). Moreover, applying the per-unit-area factors from Deng et al.[7] to our global area values, we see that forestry now moves from third to second place in driving carbon sequestration losses, moving closer to the value for cropland (Table 1, row 5). While such a rough calculation has to be treated with great care, as it ignores the large spatial heterogeneity of SOC responses to land use, it suggests that including SOC would not change our overall messages regarding the impacts of forestry on carbon storage. In fact, these calculations suggest that including SOC reinforces the contribution of forestry to lost carbon sequestration potential, the opposite of what Duarte-Guardia et al.[2] imply.

Regarding the point that "The effects of LUC on aboveground C and net C sequestration are transient"[2], we concur that land-use effects on carbon fluxes are transient until steady states of in- and outfluxes are reached. This holds for the method we used for calculations of cropland and grazing lands, as well as that employed for forestry and our therefore "indicator reflects short-to-medium term conditions only"[1]. However, as long as land continues to be used, the impacts of land use on carbon stocks are not transient. Forestry reduces biomass stocks of forests compared with their untouched counterparts even under sustainable forest yield management[4,8], for example.

Finally, we want to stress again that we agree with Duarte-Guardia et al.[2] that efforts to include SOC and related implications (such as soil degradation) in future analyses are timely and will be critical for improving our understanding of land-use-induced impacts on the Earth system and their socioeconomic drivers.

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## Author contributions

T.K., A.M., K.-H.E. and H.M.P. designed the work. T.K. and A.M. wrote the paper with help from K.-H.E., H.M.P., I.S.M., C.P., M.C.T., N.E., M.A.J.H., R.W., K.S., M.B., J.C., J.P.H. and A.T.

## Competing interests

The authors declare no competing interests.

## Additional information

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