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No-tillage does not on average reduce soil carbon storage compared to conventional tillage. Comment on “Declines in soil carbon storage under no tillage can be alleviated in the long run” by Cai et al.

Cai et al. (2022) presented a meta-analysis of how no-tillage (NT) practices, in comparison to a conventional tillage (CT) practice, affect soil organic carbon (SOC) stocks. They concluded that NT, relative to CT, increased SOC only in the upper soil depth (0–10 cm) but reduced SOC in some deeper layers, leading to an overall net decrease of SOC across the profile (up to 60 cm deep; average of -0.24 Mg C ha^{-1}). As researchers interested in how agricultural conservation practices, such as NT or reduced tillage, can improve ecosystem services like soil carbon storage, we were surprised by these results: several past meta-analyses on the same topic arrived at opposite conclusions (e.g., Meurer et al., 2018; Nicoloso and Rice, 2021; West and Post, 2002). After re-analysis of the data presented by Cai et al. (2022), we found that the data do not support the authors’ conclusions but rather show support for NT as preferable to CT as a SOC storage practice.

First, we worked through the authors’ analysis to understand how their data were used to generate their results and conclusions (Appendix A). We found several flaws, but perhaps the most important one for the study’s conclusions was the approach of discretizing (or ‘binning’) soil layer data, summarizing by bin, and then aggregating across bins to infer changes in SOC stocks between tillage practices. This handling, among other issues, ignores dependencies among the data such as those derived from specific soil layers originating from the same soil profile (averaged for an experimental unit) and ignores how studies contribute observations to some soil depth bins but not others. Other flaws in the analysis related to some conceptual challenges specific to this topic. For example, Cai et al. compare SOC stocks between tillage practices on a fixed depth basis although it is generally accepted now that equivalent masses should be used (von Haden et al., 2020; Wendt and Hauser, 2013). Our assessment explains some of the perplexing results in Cai et al. (2022). For example, Fig. 1b in Cai et al. (2022) suggests an approximate 2 Mg ha^{-1} difference in SOC stocks between NT and CT within 3 years after establishing the tillage practices. This puzzling plunge in SOC is not supported theoretically or empirically. We suggest it is rather an artifact of the authors’ data handling.

Second, we used the data in Cai et al. (2022) to offer an alternative re-analysis that partly overcomes the limitations in their analysis (Appendix B). We re-analyzed the paired data of SOC stocks under NT and CT without binning soil layer data. Instead, we pursued Cai et al.’s emphasis of the “entire soil profile” when comparing NT and CT. Therefore, we aggregated the data originally given as individual soil layers (for example, SOC stocks per sampled depth for a study that sampled 0–5, 5–15, and 15–30 cm) to obtain whole-profile[1] SOC stocks (e.g., 0–30 cm) to the deepest extent sampled (up to 100 cm), which then formed the basis for our analysis.[2] This contrasts with the analysis by Cai et al. (2022) of individual layer SOC stocks within distinct, arbitrary depth classes.

For the observations in their dataset covering depths greater than 20 cm, we find that most pairs show greater whole-profile SOC stocks for NT than for CT (Fig. 1). Going further, we used these paired, whole-profile SOC stocks in a simple meta-analysis. We calculated the log response ratio (logRR) as:

$$logRR = log\left(\frac{C_{NT}}{C_{CT}}\right)$$

where C is the whole-profile SOC stock (Mg C ha^{-1}) for the respective tillage treatments and log is the natural log. We calculated the variance in logRR following Rosenberg et al. (2013). More details are in Appendix B.

We did not include several moderating variables of interest in the meta-analytic model as they were either not included in the authors’ database (e.g., tillage intensity) or had missing observations (all climatic, soil, and management columns had missing data, which is a common challenge in meta-analysis). We did, however, include the tillage practice duration to assess how the logRR changes with time. Consistent with how data pairs generally fall above the 1:1 line in Fig. 1, the intercept in the meta-analytic model (Fig. 2) was positive (5.1% greater whole-profile SOC stocks under NT; 95% credible interval, 3.0 to 7.2%). Additionally, the mean effect of tillage practice duration followed a monotonic, nonlinear increase in the NT effect over time, peaking around 8% after 20 years; this corroborates the general finding that SOC sequestration following conversion to NT (if any) requires some years to establish (West and Post, 2002). In Appendix B, we repeated this analysis but retained soil profiles as shallow as 20 cm to include an additional 74 paired observations; the results are similar to those here albeit there is risk that the paired data are too shallow for a fair comparison of tillage practices (details in Appendix B).

[1] We use the term ‘whole-profile’ here to mean ‘from the surface to the deepest extent of the soil sampled in the study’; we note this does not refer to the true entire soil profile, which is rarely sampled in the studies of this literature.

[2] We do not know the primary studies used in Cai et al. (2022) because the authors did not provide the literature comprising their *meta*-analysis either in text or in their supplemental materials. However, using a pseudo-grouping variable for our re-analysis (see Appendix B) suggests that out of 277 ‘groups’ of data in the spreadsheet, 94 had at least one pair of soil profiles with contiguous soil layers that extended beyond a 20 cm depth. These groups provided the 110 pairs of whole-profile SOC stocks in our re-analysis.

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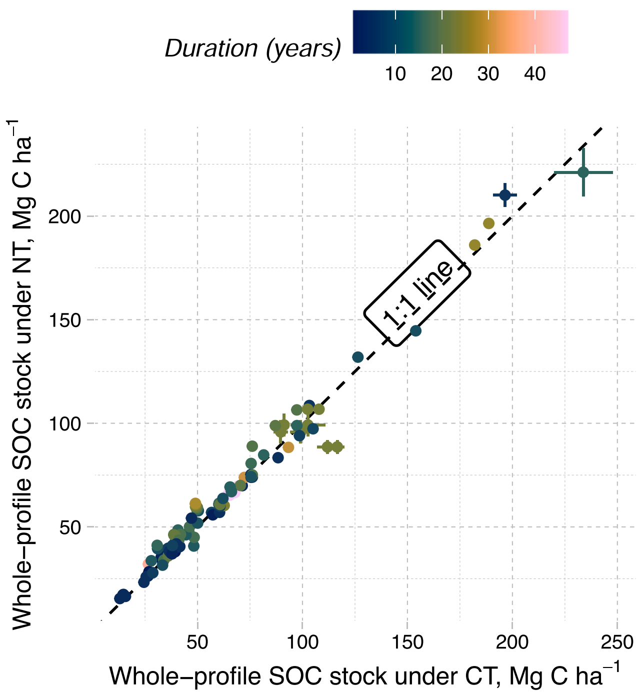

Fig. 1. Whole-profile soil organic carbon (SOC) stocks calculated from the data compiled by Cai et al. (2022) for profiles greater than 20 cm depth (range from 30 to 100 cm deep, median of 30 cm) resulted in 110 paired comparisons between no-tillage (NT) and conventional tillage (CT). It is likely that some studies provided multiple pairs. Lines are standard errors from calculating the cumulative sum stock over depth. For these pairs of data, 67% fall above the 1:1 line, indicating that NT whole-profile SOC stocks are typically greater than their CT reference.

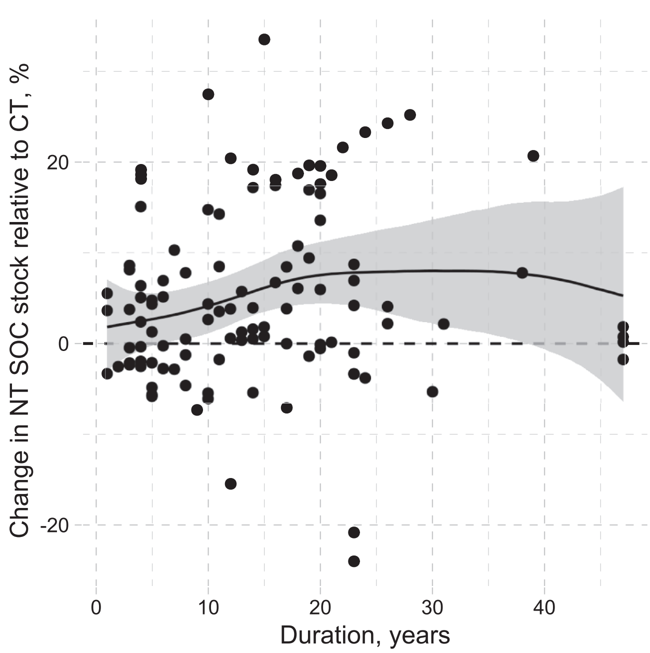

Fig. 2. Using a simple meta-analytical model of the paired whole-profile soil organic carbon (SOC) stocks provided by Cai et al. (2022), the duration of tillage practice shows an increase in the no-tillage (NT) effect on SOC, relative to conventional tillage (CT), up to ~ 20 years. The curve is the modeled mean effect and its 95% credible interval is shaded.

These results, using data provided by Cai et al. (2022), run counter to the authors' conclusions. If NT reduced SOC stocks "in the entire soil profile", then the actual whole-profile stock data available do not reflect it, but rather the opposite (Figs. 1 & 2). Previous reviews and meta-analyses have likewise found modest support, or a neutral effect, for NT in promoting more SOC storage compared to CT (Meurer et al., 2018; Nicoloso and Rice, 2021; West and Post, 2002). We generally agree with Cai et al. (2022) that "NT alone should not be promoted as a panacea for climate change mitigation". Compared to conventional practice, NT is but one management tool that generally can increase SOC stocks, but this is not guaranteed, particularly when adopted without other agricultural conservation practices (e.g., cover crops, diverse rotations). NT or reduced tillage is also effective at enhancing a variety of other ecosystem services crucial to sustainable agriculture but its potential for promoting SOC storage is context-dependent (Baker et al., 2007; Powlson et al., 2014). The literature, however, including studies used by Cai et al., do not support the claim that NT on average decreases SOC storage compared to CT (Cai et al., 2022).

Meta-analyses on topics of conservation agriculture and ecosystem service outcomes are crucial for statistically synthesizing information, improving predictions of management outcomes, and for guiding better policy for sustainable agriculture. Yet, meta-analyses must be rigorous, transparent, and robust to be useful (Philibert et al., 2012). Regardless of differences in the approaches described above, many key elements of meta-analysis are missing in the data analysis provided by Cai et al. (2022). For example, the requisite systematic literature review for the meta-analysis is not described sufficiently and the actual literature comprising the meta-analysis is not cited in the authors' supplemental information. In other words, the reader cannot find out what went into this meta-analysis. Guidelines exist for executing and reporting meta-analyses (Page et al., 2021) and are adaptable to agronomic or environmental meta-analyses; these not only promote robust conclusions but encourage wider engagement from the scientific community who may corroborate or challenge the results with different methodologies. Further, a meta-analysis of tillage effects on SOC stocks on the global scale necessitates several moderators to treat observations as exchangeable (Eagle et al., 2017): the tillage response in a flooded rice paddy system in south Asia will invariably be different from that of a maize-soybean rotation in the Midwestern US, but these important contextual differences are not captured in the analysis by Cai et al. (nor in our re-analysis). Tillage systems differ and even definitions of "no-tillage" and "conventional tillage" can vary widely between studies. Hence, pooling disparate studies in an analysis without careful treatment of what actual population they represent is hazardous for making inferences. Careful, technical treatment of the specific topic is also needed for a reliable meta-analysis. For example, tillage can significantly affect SOC stocks with depth just through soil mass re-distribution, therefore comparing SOC stocks on equivalent soil mass basis is vital for evaluating tillage practices (von Haden et al., 2020). We urge editors, reviewers, and authors to treat meta-analyses more critically and enforce a stricter quality lest our inferences at the meta-analysis scale lead science, agricultural policy, and the practice of farming astray.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary data

As supplements to our letter, we provide two appendices. Appendix A steps through the primary results of Cai et al. (2022) and how they were arrived at (including R code); with a clearer understanding of what the authors did, we highlight points of error or inappropriate analysis in addition to further discussion of the challenges facing this meta-analysis. Appendix B details our re-analysis of the data in Cai et al. (2022), including R code, details on data treatment, and statistical analyses. Supplementary data to this article can be found online at https://doi.org/10.1016/j.geoderma.2022.116307.

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