These findings diverge sharply from predictions made by process-based SOC models that also incorporate soil texture and water content to resolve SOC changes with crop management. These models[2–4], well constrained and broadly tested in a wide variety of soils, climates and cropping systems in the Midwest and elsewhere, almost universally predict stable or increasing SOC with full residue retention under no-till management in Midwest soils[5]. Soil inventory models[6] also show stable or increasing SOC across the Midwest, as do global inventories[7]. We are unprepared to explain the basis for the anomalous behaviour of the Mead, Nebraska site, but a very low root-shoot ratio of ~0.07 (Supplementary Table 3 in ref. 1), which likely underestimates root carbon inputs, may explain part of the difference, as might irrigation, which can accelerate decomposition.

Furthermore, under no-till management scenarios that remove a substantial proportion of corn residue, process-based models typically predict stable long-term SOC stocks on conversion from standard tillage. In one such study[8], for example, the DayCent model estimated that up to 70% of corn stover can be removed from a typical Iowa soil without SOC loss. These patterns can be explained in part by the disproportionate contribution of roots to stabilized SOC[9] and in part by a more realistic characterization of decomposition rates under different soil × climate conditions. While we agree with Liska *et al.* that full residue removal without cover crops will likely deplete SOC over the long term — although at a much lower rate than they estimate — this is an unrealistic scenario: we are not aware of any management practices for corn grain production that prescribe 100% stover removal.

Finally, while we agree with the motivation that underlies their analysis — there is a pressing need to understand the full climate impact of biofuels in general and stover removal in particular — we believe that this is best achieved with efforts that are based on our full understanding of carbon turnover in agricultural soils, and not on models that unduly simplify important relationships. ❐

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Reply to ‘CO_2 emissions from crop residue-derived biofuels’

Liska *et al.* reply — The soil organic carbon (SOC) model that we used[1] was parameterized with data from arable land under normal farming conditions in North America, Europe, Africa and Asia[2], but the equation is insensitive to changes in tillage, soil texture and moisture. The model has reasonable accuracy, however, in predicting changes in SOC, residue remaining and CO_2 emissions from initial SOC, carbon inputs from residue, and daily temperature[1,2]; the shoot-to-root ratio used in the geospatial simulation was 0.29 (that is, root carbon is 29% of total aboveground carbon), which did not underestimate carbon input to soil (Supplementary Fig. 2 in ref. 1). There is more theoretical confidence in the conserved nature of SOC oxidation due to temperature[1–5] relative to other factors such as tillage[6–8]. In a recent comparison of three SOC models (CENTURY, DAYCENT and DNDC), predictions were close to or within the range of uncertainty of estimates derived from soil measurements, showing that these models tend to produce similar results from residue removal[5]. (A range of soil measurements have also shown net SOC loss from residue removal[1,5].) The model also agreed well with CO_2 emissions measurements from an AmeriFlux field site[1], which since 2000 has been funded with $7,370,000 from the US Department of Energy, the US Department of Agriculture and NASA, leading to over 85 peer-reviewed publications.

The question for life cycle assessment (LCA)[1] is: what is the net change in SOC compared with a counterfactual situation where residue is not removed? It seems that the logic of this question has not been recognized by the US Department of Agriculture[9] or US Department of Energy[10]. Simulations with 2, 4 and 6 Mg ha^{-1} yr^{-1} residue removal in the Corn Belt, corresponding to ~25, ~50 and ~75–100% of corn residue produced in a single year, respectively, each resulted in a net SOC loss compared with no removal, which is difficult to measure in soil in less than 5 years but can be estimated confidently using models[1,3,5]. Importantly, when SOC losses are normalized for the energy in the biofuel derived from residue, roughly equivalent CO_2 intensities are estimated regardless of the amount of residue removed (Fig. 2c in ref. 1) — a central finding of our research.

The question for LCA is also not: how could these systems be in the future? The question is, however: how are these systems performing now, and how are they going to perform in the near term? The lignin coproduct is burned to provide energy for biofuel processing, and currently no electricity exports or other coproducts exist in the Poet's Liberty project (http://poet-dsm.com/liberty). Potential electricity output from burning lignin could also be 69% lower than the estimate previously provided (that is, −17 g CO_2 equivalent MJ^{-1} versus −55 g CO_2 equivalent MJ^{-1})[1,10]. The lignin oxidized in biofuel processing is the SOC that is lost, because that lignin would have oxidized more slowly in soil[1–4].

Standards for LCA are under development and in a state of flux. Owing to the complexity of LCA, a wide range of values can be produced in these assessments due to arbitrary variability in spatial and temporal parameter values, modelling assumptions, timeframes and system boundaries[11,12]. Consequently, our analysis focused on quantifying uncertainty in one primary variable: net SOC loss to CO_2 from residue removal[1]. The 30-year time interval precedent set by Searchinger *et al.* is arbitrary and biases results in favour of biofuel producers[12,13]. Precedents used by the US Environmental Protection Agency may not favour near-term emissions reductions, and existing precedents will probably be revised. To accurately represent current climatic conditions and SOC dynamics, temperature measurements from 2001 to 2010 were used[1], because older data do not represent increased temperatures and future projections are more uncertain. The model[1], however, was also used to estimate SOC changes from 2010 to 2060 with estimated increases in crop yields and temperatures from the IPCC's Fifth Assessment Report climate simulations (representative concentration pathway 8.5 emissions scenario)[14]. When compared with no residue removal, removal of 3 Mg ha^{-1} yr^{-1} of residue from continuous corn was estimated to lose ~0.22 Mg C ha^{-1} yr^{-1} on average in the first 10 years in three counties in Nebraska and Iowa; for the first 30 years, this value was reduced by ~52% on average to ~0.11 Mg C ha^{-1} yr^{-1} (ref. 14).

Yet, to dilute SOC emissions over 30 years or more does not represent actual CO_2 emissions over the first 10 years, and presenting longer-term lower values can be deceptive. Sanchez *et al.* noted, "Policymakers may find it appropriate to focus on more certain, near-term climate impacts, in which case a short horizon for fuel warming potential is sufficient."[12] If residue is removed for biofuel, these systems could produce more CO_2 emissions than gasoline for more than 10 years (ref. 1) and then possibly reduce emissions in 20 to 30 years, after agricultural SOC stocks have significantly decreased and crop yields have probably declined. Alternatively, SOC loss from residue removal can be widely recognized, and appropriate management can be used to compensate for lost carbon and increased CO_2 emissions[1]. ❐

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Lessons learned from geoengineering freshwater systems

To the Editor — Our ecosystems and the services they provide are increasingly being degraded by multiple and interacting pressures. Humans are using geoengineering to mitigate their effects, even though it commonly addresses acute symptoms of single pressures. Barrett *et al.*[1] discuss the benefits, problems and geopolitical consequences of proposed geoengineering to alleviate the effects of climate change by injecting sulphate into the stratosphere. This is an untried, global measure, the efficacy of which is difficult to predict[2]. However, geoengineering is already being applied in fresh waters, at smaller scales, using additives to alleviate the effects of either local nutrient enrichment or regional acid deposition[3]. Lessons from these and other freshwater management experiences provide empirical evidence to reinforce the conclusions of Barrett *et al*. Here, we highlight the need to consider feedbacks between ecosystems and the pressures acting on them beyond the potential interactions in their Fig. 1.

Barrett *et al.*[1] discuss various environmental problems that stratospheric sulphate injection cannot solve, such as Antarctic ice loss and indirect effects on precipitation. Similarly, in fresh waters, phosphorus reduction using geoengineering will not alter the widespread effects of nitrogen enrichment[4]. Barrett *et al.*[1] point out that geoengineering will not return the climate to past conditions. The same is also true in lakes for phosphorus removal, and for natural or artificial recovery from acidification, where multiple pressures produce novel ecosystems[5]. Mitigation of climate change by sulphate injection could reduce the pressure on politicians to lessen carbon emissions. In fresh waters, there is a similar concern that geoengineering will reduce the pressure on regulators to manage nutrient loss from the catchment[3].

These limitations seem to be common across scales, but there are also positive and negative feedbacks of geoengineering that are difficult to predict. For example, a cooled climate may alleviate eutrophication symptoms in fresh waters, such as cyanobacterial blooms or the effects of rapid expansion of non-native species from warmer areas[6]. A decrease in phosphorus following rapid phosphorus control using geoengineering in fresh waters is likely to favour a decrease in methane ebullition from lakes to the atmosphere[7]. Altering weather may change catchment productivity, which is also linked to carbon dioxide losses to the atmosphere from lakes[8]. Both climate mitigation and phosphorus control are likely to reduce coastal fish stocks, compounding the negative socioeconomic effects of overfishing[9].

Management of climate systems may cause geopolitical problems that benefit