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Reply to 'CO_2 emissions from crop residue-derived biofuels'*

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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 Figure 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 (Figure 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

* The "Reply" addresses 3 commentaries preceding it in this issue:

1. by Niclas Scott Bentsen, Søren Larsen, and Claus Felby of Department of Geosciences and Natural Resource Management, Faculty of Science, University of Copenhagen, Rolighedsvej 23, DK-1958 Frederiksberg C, Denmark. *Nature Climate Change* 4:11 (Nov 2014), p. 932; doi: 10.1038/nclimate2401 (Published online 29 October 2014). http://www.nature.com/nclimate/journal/v4/n11/full/nclimate2401.html
2. by John J. Sheehan, Paul R. Adler, Stephen J. Del Grosso, Mark Easter, William Parton, Keith Paustian, and Stephen Williams, of Department of Soil and Crop Sciences, Colorado State University, Fort Collins, Colorado (Sheehan & Paustian); US Department of Agriculture Agricultural Research Service, Pasture Systems and Watershed Management Research Unit, University Park, Pennsylvania 16802, USA (Adler); US Department of Agriculture Agricultural Research Service, Soil Plant Nutrient Research Unit, Fort Collins, Colorado 80526, USA (Del Grosso); Natural Resources Ecology Laboratory, Colorado State University, Fort Collins, Colordao 80523, USA (Easter, Parton, Paustian & Williams). *Nature Climate Change* 4:11 (Nov 2014), pp 932–933; doi: 10.1038/nclimate2403 (Published online 29 October 2014). http://www.nature.com/nclimate/journal/v4/n11/full/nclimate2403.html
3. by G. Philip Robertson, Peter R. Grace, R. César Izaurralde, William P. Parton, and Xuesong Zhang, of Department of Plant, Soil, and Microbial Sciences and W.K. Kellogg Biological Station, Michigan State University, Hickory Corners, Michigan 49060, USA (Robertson); Great Lakes Bioenergy Research Center, Michigan State University, East Lansing, Michigan 48824, USA (Robertson, Izaurralde, & Zhang); Institute for Future Environments, Queensland University of Technology, Brisbane, Queensland 4000, Australia (Grace); Department of Geographical Sciences, University of Maryland, College Park, Maryland 20740, USA (Izaurralde); Texas AgriLife Research, Texas A&M University, Temple, Texas 76502, USA (Izaurralde); Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, Colorado 80521, USA (Parton); and Joint Global Change Research Institute, Pacific Northwest National Laboratory, University of Maryland, College Park, Maryland 20740, USA (Zhang). *Nature Climate Change* 4:11 (Nov 2014), pp 933–934; doi: 10.1038/nclimate2402 (Published online 29 October 2014). http://www.nature.com/nclimate/journal/v4/n11/full/nclimate2402.html

Those commentaries address the article "Biofuels from crop residue can reduce soil carbon and increase CO_2 emissions," by Adam J. Liska, Haishun Yang, Maribeth Milner, Steve Goddard, Humberto Blanco-Canqui, Matthew P. Pelton, Xiao X. Fang, Haitao Zhu, and Andrew E. Suyker. *Nature Climate Change* 4:5 (May 2014), pp 398–401; doi: 10.1038/nclimate2187 (Published online 20 April 2014). http://www.nature.com/nclimate/journal/v4/n5/full/nclimate2187.html or http://digitalcommons.unl.edu/bseliska/16/

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 favor 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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