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Environmental Impacts of Large Scale Biochar Application Through Spatial Modeling

Introduction & Objectives

Corn production in the US Midwest has the potential to generate a large amount of crop residue for bioenergy production. However, unconstrained harvesting of crop residues is associated with a long-term decline in soil quality and environmental benefits. Biochar applications can mitigate many of the negative effects of residue removal but regional scales analyses to support decision making are lacking. The **objectives** of this study are:

1) to develop an integrated system to predict impacts of biochar applications at regional scales, and
2) to investigate, regional variation in the long-term effects of biochar application and residue removal practices on maize productivity, soil organic carbon levels, and nitrate leaching across the US Midwest.

Methodology

We coupled the APSIM biochar model (version 7.9; Holzworth et al., 2014; Archontoulis et al., 2016) within the pSIMS platform (version 2.0; Elliot et al., 2014) to simulate four scenarios:

Baseline: continuous corn over 30 years under no-till

Scenario I: Baseline plus a single biochar application of 12 Mg/ha

Scenario II: Baseline plus 50% corn residue removal every year

Scenario III: Baseline plus biochar plus residue removal (scenarios I and II)

We focus our simulation analysis on three Midwestern states, Iowa, Illinois and Indiana that cumulative account for the 62% of the US row crop land. The simulation process was sequential, staring in 1980 and ending in 2010 at a 10-arcminutes resolution (about 1000 simulations per state). Soil information retrieved from the Global Soil Dataset for Earth Systems Modeling and weather information from AgMERRA global weather database. Management information such as planting dates and hybrids maturity for each cell were derived from NASS statistics and local sources. N fertilizer application rate was 220 kg N/ha/yr and plant density was 7 pl m^{-2}. Biochar incorporated to a depth of 30 cm in year 1990. The biochar had a carbon fraction of 78%, CN ratio of 132, labile fraction of 13%, and mean residence times for the labile and recalcitrant biochar pools of 1 and 500 years, respectively. Priming effects of biochar were deactivated but biochar effects on pH, CEC, soil water characteristics, N cycling were all activated in the simulation process (Fig. 1). Outputs from the model were: corn yields, soil organic carbon in different layers, GHG emissions (N_2O and CO_2), complete water and N balances that include N mineralization, immobilization, denitrification, and N leaching, evapotranspiration, and changes in plant available water and soil porosity. The APSIM biochar model has been previously calibrated and validated at field scale (Archontoulis et al., 2016; Aller et al under review; Laird, unpublished data) showing acceptable performance.

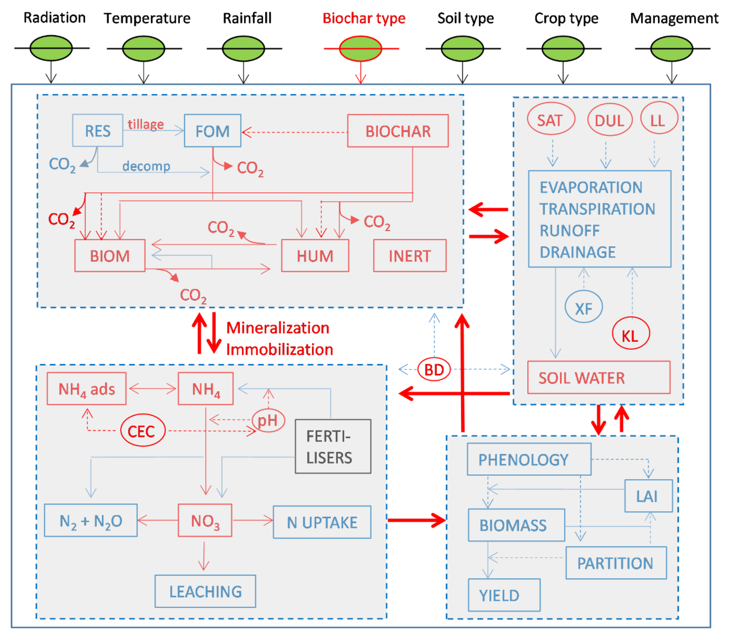


Fig. 1: Overview of the biochar model (biochar influences red arrows and boxes) within the APSIM simulation platform (Archontoulis et al., 2016)

Fig. 2: View of biochar application in the field

Results

Soil Organic Carbon (SOC): Compared to the baseline simulations, the biochar scenario resulted in 8.9% higher SOC levels (0-30 cm depth), the residue removal scenario in 5.4% lower SOC levels and the combined biochar and residue removal scenario in 3.6% higher regional average SOC levels after 20 years. (Fig. 3a). C sequestration in Gt per state is shown in Fig 4a. After 20 years, 85% of the applied biochar was still in the soil.

Soil Water: Compared to the baseline, a single biochar application increased average soil water holding capacity and porosity in the topsoil (0-30 cm) by 1.4% and 3.1%, respectively. The residue removal scenario slightly decreased porosity and soil water holding capacity. The water field pore space (ratio of soil water to saturation) decreased by 1.3% under both biochar and residue removal scenarios for different reasons; increased porosity in the biochar scenario and decreased soil water in the residue removal scenario.

Soil Nitrogen: Compared to the baseline, a single biochar application decreased N losses to leaching (below 120 cm soil depth) and denitrification by 1.7% on average across the 3 states and 20 years of simulations (Fig. 3b; 4b). Residue removal decreased N losses by 19.4% and residue removal plus biochar application together by 21.2% compared to the baseline. The reasons are: a) temporal immobilization of inorganic N caused by biochar decomposition and b) the decline in SOC under residue removal practices decrease the production of inorganic N via soil N mineralization (Fig. 3a). The majority of N loss reduction derived from reduction in N leaching and not from the denitrification. Residue removal decreased N losses more that the biochar because of the increased loss of soil water to evaporation and runoff that decreased soil water loss to drainage, the driver of NO_3 leaching.

Crop Yields: A single biochar application on average increased corn yields by 0.48, 0.65 and 0.53% in Iowa, Illinois and Indiana, respectively (Fig. 3c) Assuming a corn price of 4 $/bushel this yield increase is translated to an additional gross revenue of 40, 49 and 21 million $ per year for Iowa, Illinois and Indiana, respectively. Across the three states, the annual residue removal reduced yield by an average value of 0.75% that is 64 million $ loss per year. The single biochar application offset 45% of this decline, which means that *addition of biochar enhances the long term sustainability of crop residue harvesting*. Future cost-benefit analyses should account for the price of harvesting/selling 31 million Mg per year of residue across the three states.

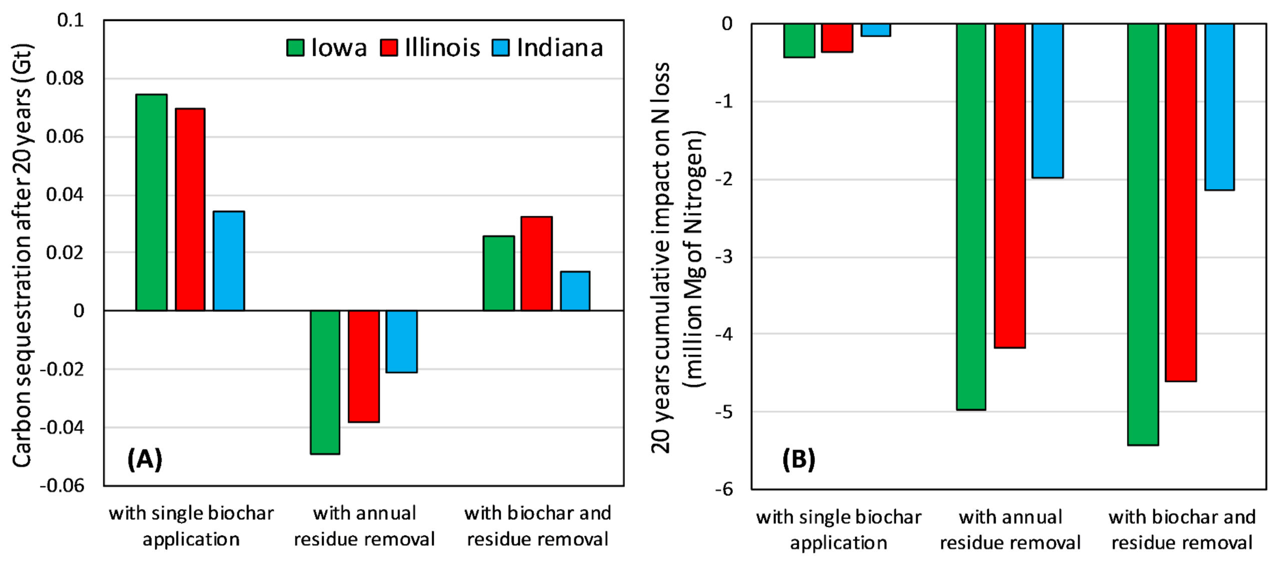


Fig. 4: (A) Carbon sequestration 20 years after applying biochar and/or residue removal scenarios compared to the baseline, and (B) cumulative N losses over 20 years of applying the different scenarios compared to the baseline.

Fig. 3a: Effect on SOC compared to baseline

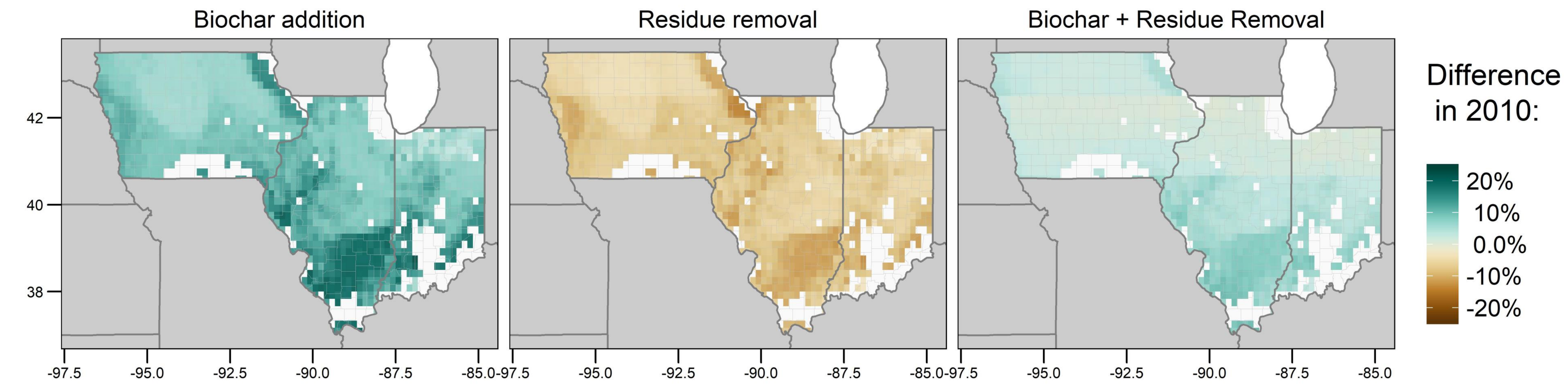


Fig. 3b: Effect on nitrogen loss compared to baseline

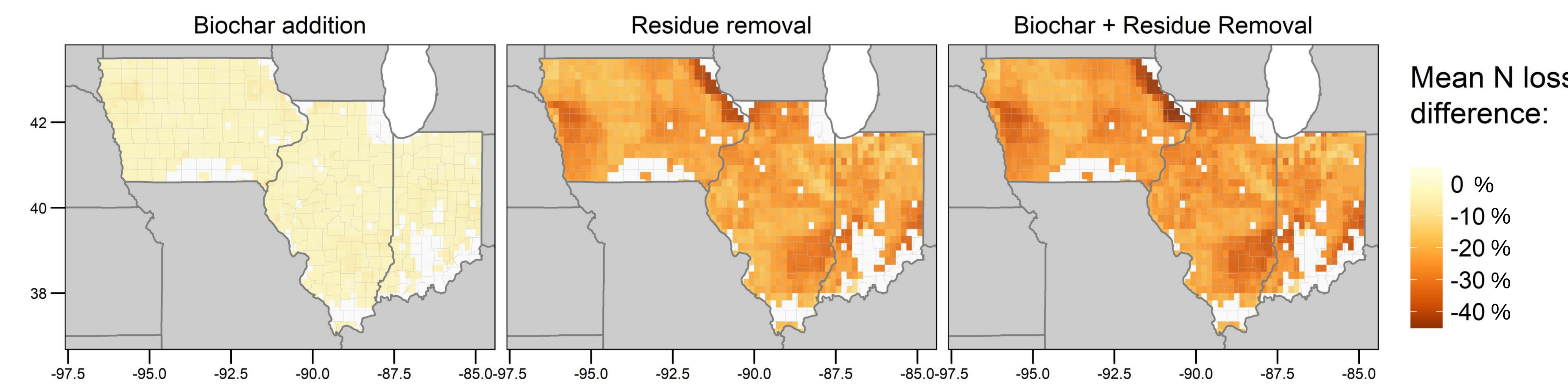
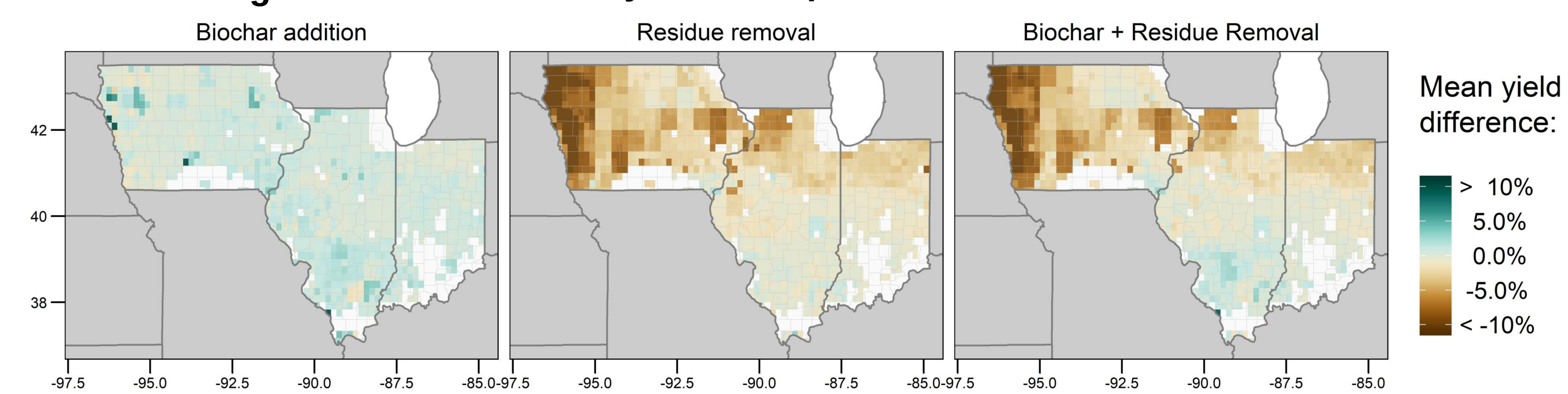


Fig. 3c: Effect on maize yields compared to baseline



Conclusions

- The APSIM-biochar model coupled with the pSIMS framework is useful in predicting impacts, showing regional differences, explaining causes and exploring management decisions strategies.
- Biochar caused large SOC increases and N leaching decreases, but had little effect on N_2O emissions or crop yields.
- The scenario analyzed here assumed that 272 million Mg of biochar were available for application in the Midwest (12 Mg/ha application rate). This amount of biochar does not currently exist in the Midwest. To generate this amount of biochar from corn residue it will take about 6-12 years assuming a 20% conversion efficiency of crop residue to biochar.
- Future scenarios should explore application of small biochar amounts (i.e. 1 Mg/ha) every year, amounts that realistically may be available in the Midwest and/or on-time strategic applications of large amounts of biochar on degraded soils. APSIM coupled with pSIMS allows impacts of these scenarios to be evaluated at regional scale and over long periods of time.

References:

Archontoulis SV, Huber I, Miguez F, Thorburn P, Rogovska N, Laird D, 2016. A model for mechanistic and system assessments of biochar effects on soils and crops and trade-offs. *GCB-Bioenergy* 8, 1028-1045

Elliot J, Kelly D, Chyssanthacopoulos J et al. 2014. The parallel system for integrating impacts models and sectors (pSIMS). *Environmental Modeling & Software* 62, 509-516.

Holzworth D, Huth N, de Voil P et al., 2014. APSIM – evolution towards a new generation of agricultural systems simulation. *Environmental Modeling & Software* 62, 327-350.

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