# Abstract

The long-term carbon balance of the agricultural Midwestern United States will depend on the interactions between climate, land use decisions, plant biology, and biogeochemistry. In agricultural systems, C storage is fully determined by belowground pools, so it is vital to understand the links between root placement and C status under a variety of potential future conditions and land use types. I considered three such links: the long-term trajectory of soil C in a conventional maize-soybean rotation subjected to climate change, the potentially major increase in root C inputs associated with a change from row crops to high-yielding perennial grasses (*Miscanthus* *giganteus* and *Panicum virgatum*), and the taxonomic partitioning of vertical niche space in a restored prairie.

To determine the effect of climate change on soil C in conventional row crop agriculture, I measured root and soil respiration under soybeans and maize grown under elevated temperature (ambient + ~2 °C) and elevated CO2 (+200 ppm) for three years, then used a process-based ecosystem model (DayCent) to extend these observations and infer long-term changes in soil C. Heating and CO2 both increased microbial respiration by ~20%, and heating reduced root respiration by ~25%. Particulate organic matter was lower in elevated CO2 plots, possibly indicating a CO2 priming effect on the loss of old soil carbon. DayCent results agreed with heated-plot observations but did not resolve the speculated CO2 priming effect, because the model has no mechanism to simulate priming. Over the next several decades, I predict a substantial loss of C from agricultural soils.

To clarify differences in root architecture between several potential biofuel crops, I collected minirhizotron images from 0-100 cm depth over five growing seasons from a maize-maize-soybean row crop rotation and from three perennial grasses. I developed a Bayesian statistical model that accounts for near-surface underdetection effects and correctly handles the frequent zero counts typical of minirhizotron data. The model performed well against direct measurements from deep cores and allowed improved inferences about the amount of root allocated to each soil layer and how it changes through time. Mature perennial crops showed little change in relative allocation through time, but total root volume of perennial grasses increased dramatically from 2010 to 2014 and showed little change during a historic drought in 2012, implying that these large, deep root systems confer drought tolerance. By growing exceptionally large, fine, highly-dispersed root systems that sent substantial amounts of C into very deep soil, land use conversion from row crops to perennial grass biofuels is likely to create a large and persistent C sink.

To learn how species arrange themselves in space within complex communities and infer their roles in C cycling, I used a DNA metabarcoding approach to identify the *ITS2* sequences of taxa present in mixed root samples from varying depths (0-10, 10-30, 30-50, 50-75, 75-100 cm) in a restored prairie and looked for evidence of taxonomic partitioning. Spatial patterning was strongest between functional groups, with the prevalence of grasses increasing and of forbs decreasing with depth. Pairs of taxa with one from Asteraceae and one from Poaceae tended to co-occur with each other less often than expected by chance (spatial segregation), while most other pairs of taxa were found to co-occur randomly or positively, indicating that there is little spatial partitioning at this site other than the depth of grass roots. This may indicate that grass roots are disproportionately important for deep-soil functions that affect the resilience of the whole ecosystem, such as water uptake, N leaching prevention, and C storage.

Overall, this research highlights that business as usual will probably not be a tenable response to climate change and that a shift from row cropping toward perennial grass biofuel systems, either in the form of high-yield monocultures or as low-input high-diversity systems, is likely to promote C storage. However, the time horizons required for significant accumulation are long (decades to generations) and policies intended to promote C storage will only be effective if they provide incentives structured for long-term stability.