Innovations to the DayCent Biogeochemical Model to Better Simulate Carbon and Nitrogen Cycling in Bioenergy Crop Systems with Increasing Climate Variability

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Project Goals: This project addresses advances in biogeochemical modeling to simulate carbon and nitrogen fluxes under varying environmental conditions so they may better quantify the extent that bioenergy crops could mitigate climate change. First, we are amending the DayCent biogeochemical model's soil module to include microbial enzyme kinetics to improve temperature and moisture response of decomposition. Second, DayCent has been updated to better simulate the unique structural and physiological attributes of perennial bioenergy grasses. Third, we are working on incorporating plant physiological responses to waterlogged soils. There is potential for flood-tolerant bioenergy crops to mitigate losses of corn and soybeans to extreme precipitation and inundation events, and we are using modeling experiments to evaluate the greenhouse gas (GHG) implications of converting flood-susceptible fields to switchgrass or miscanthus.

Soil carbon sequestration is a key component to understanding the sustainability of bioenergy feedstocks and the role they could play to mitigate climate change. Because field experiments are limited in temporal and spatial scales, using ecosystem models to simulate soil carbon fluxes in tandem with field experiments are key to understanding how policy and management decisions will affect long-term carbon sequestration and storage. Century, the monthly timestep of the DayCent biogeochemical model, has served as one of the foundational frameworks for soil carbon modeling. In recent years, there has been a call to include microbial explicit processes in soil modeling in order to better represent decomposition and soil carbon stabilization in response to warming, rewetting, and root-priming. Microbial explicit soil models have been developed in the last decade. However, they have not been widely adapted into ecosystem or Earth System scale models. Here, we are incorporating microbial process-based equations from FUN-CORPSE (a pairing of the Fixation and Uptake of Nitrogen model with the Carbon, Organisms, Rhizosphere, and Protection in the Soil Environment model) into DayCent's soil module. The new version of the model will use reverse Michaelis-Menten kinetics in the decomposition function that relates to microbial enzyme activity rather than the current decay rate-driven first order kinetic equations. To do this, the model will have explicit live microbial biomass pools in the surface and soil layers within the current DayCent model structure as well as dead microbial carbon pools that transfer directly to the passive soil carbon pool. This will allow for microbial growth and biomass to influence the rate of decomposition and represent the affinity of microbial necromass to become physically protected. Advances made with this work can serve as an example of how to improve the representation of microbial functions for Century-based soil models in a number of ecosystem and Earth System models.

Bioenergy feedstocks such as miscanthus, switchgrass, sugarcane, and sorghum have unique structural and physiological attributes that influence carbon and nitrogen cycling. To simulate long-term dynamics of these fast-growing, high productivity bioenergy crops, we developed a new bioenergy grass PFT with additional physiological parameters for DayCent. The new PFT separates leaves and stems into separate pools rather than a single aboveground biomass pool, and it represents rhizomes as well as fine roots. This allows for leaves and stems to be parameterized with separate C:N ratios and lignin content. The new version simulates re-translocation of nitrogen from leaves to rhizomes during senescence. This stored nitrogen is then available for growth during the next growing season, allowing plant health during one growing season to affect plant growth during the next. Additionally, separation of stems and leaves can help modelers better estimate useable biomass for biofuel production.

The Renewable Fuel Standard (RFS) calls for increasing the volume of cellulosic biofuel while reducing lifecycle GHG emissions by 60%. While conversion of land used for corn-soy production to perennial, cellulosic bioenergy crops has been a controversial topic, it is becoming increasingly apparent that it will be difficult to meet GHG reduction targets only by converting uncultivated land to perennial bioenergy feedstock production. Currently, approximately 40% of corn grain is used for ethanol production and corn-soy losses have been increasing in the last decade. As much as 75% of losses are attributed to water-inundated fields. Flooding and extreme precipitation events are projected to increase due to climate change, resulting in a greater loss of corn and soy yield. Perennial bioenergy crops such as switchgrass and miscanthus are tolerant of flooding, making them a productive alternative to corn in low-lying areas that otherwise suffer recurring losses of corn and soy yield with repeat flooding events. Flooding in agricultural land typically occurs in floodplains and potholes (i.e., slightly lower-lying land that surrounding areas drain into). Figure 1 identifies counties that incurred greater than 5,000 acres of average annual losses of corn as a result of extreme precipitation and/or inundation events between 2009-2019. Using data from flooded corn, switchgrass, and miscanthus fields, we are working to improve model representation of plant physiological response to water inundation. Following model improvements, we will simulate corn-soy rotations, switchgrass, and miscanthus under current climate and increased precipitation scenarios to evaluate the GHG implications of converting corn-soy fields to perennial bioenergy crops that can withstand inundation events.

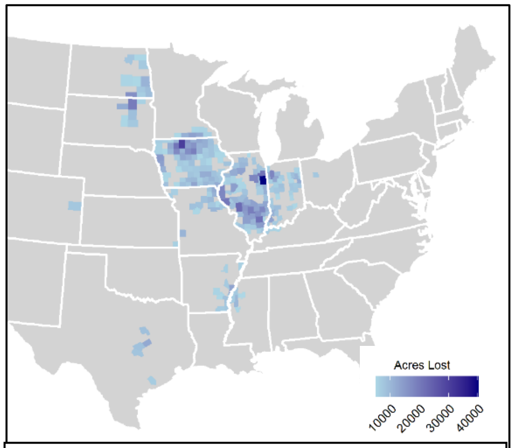

Figure 1. Average annual reported loss of acres of corn to extreme precipitation and inundation events from 2009 -2019 by county.

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