2014

Transitioning to ecologically functional production systems

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Abstract
A gap in transitioning to ecologically beneficial farming practices is the lack of understanding of how soils store carbon (C) and nitrogen (N)long term. Farmers need management practices for improving soil quality, increasing both belowground (live roots) and aboveground (live cover) biomass, increasing soil organic matter, and reducing greenhouse gas emissions. This project quantified root productivity, root decomposition, soil microbial dynamics, soil aggregation, and belowground C allocation in annual and perennial biomass cropping systems across multiple landscape positions.

Keywords
Ecology Evolution and Organismal Biology, Natural Resource Ecology and Management, Corn-soybean cropping systems, Integrated crop-livestock systems and diversity, Soils and agronomy

Disciplines
Agronomy and Crop Sciences | Ecology and Evolutionary Biology | Natural Resources and Conservation | Natural Resources Management and Policy | Sustainability

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Budget:
$41,345 for year one
$36,162 for year two
$38,623 for year three

ECOLOGY

Q How do plants and microorganisms interact to influence soil organic matter storage?

A By examining crop-microbe interactions in multiple landscape positions, PIs identified which cropping systems were best suited to increase soil carbon storage. They found that across all landscape positions switchgrass had more roots than corn, which increased the activity of soil microorganisms, especially when crops were full grown. More roots and greater microbial activity coincided with greater soil aggregation. Soil aggregation is important for storing carbon, nitrogen and water.

Background

Understanding the relationship between live roots and microbial breakdown of plant and soil organic carbon (C) pools is essential for evaluating the long-term value of each cropping system. The project team assessed differences in C storage potential among cropping systems and landscape positions by measuring microbial biomass and activity, root turnover and soil C pools. This provides a mechanistic understanding of why certain cropping systems have the potential to enhance C storage and reduce CO_2 emissions, allowing for more accurate assessments of C storage capacities.

The objectives were to:

1. Compare the microbial response (i.e., microbial biomass, extracellular enzyme activity) to conventional and alternative cropping systems grown on different landscape positions,
2. Quantify root inputs and turnover rates among conventional and alternative cropping systems grown on different landscape positions,
3. Compare soil C pools among cropping systems and landscape positions, and
4. Enhance understanding among agricultural stakeholders in how to quantify and manage soil C.

Approach and methods

Research was conducted at the Landscape Biomass Project at the ISU Uthe Research and Demonstration Farm, Boone County, Iowa. The cropping system treatments were established in 2009 on the Uthe Farm. This field experiment provided the ideal area and hillslope conditions to initiate the study. Prior to study initiation, the upland was managed under a corn-soybean rotation and vegetation in the riparian zone was composed of mixed grasses. Each treatment was randomly assigned within three replicate plots per hillslope position.

Soils at the Landscape Biomass Project include Clarion, Nicolett, Spillville and Zenor soils. Throughout the growing season Mollisols were monitored for changes in chemistry, structure and microbiological activity.

Tactics used by the team were to address the objectives and questions:

Objective 1: They tested whether microbial communities associated with a perennial cropping system differed in biomass, enzyme activity and potential mineralization rates as compared to an annual cropping system.

Objective 2: They evaluated the effects of landscape position on root growth and soil aggregation.

Objective 3: They used a total belowground carbon allocation model to compare carbon storage among cropping systems and landscape positions. They used the empirical data from Objective 2 and also measured soil carbon in aggregate fractions using a wet sieving approach and root decomposition using field decomposition cores.

Objective 4: Findings from Objectives 1 and 2 were presented in classroom lectures, national meetings, local field days, and to the Farmer Advisory Board that was assembled for this project.

Results and discussion

Results informed the development of a second-generation crop portfolio by combining an assessment (in a larger landscape biomass project) of the profitability of these novel cropping systems along with their potential to mitigate the negative effects of grain-based biofuel crops on food supply and environmental quality.

Measurements of annual root productivity of cropping systems showed the highest root production in switchgrass, while continuous corn was the lowest. Root production in annual cropping systems showed no response to topography or soil properties. Perennial systems were sensitive to topography, where switchgrass root productivity was lowest on the floodplain, and increased with higher soil sand content. For both corn and switchgrass, cropping system was a stronger driver of microbial activity than topography, with consequences for rates of decomposition. Microbial extracellular enzyme activity, respiration and net N mineralization changed in response to a perennial cropping system during peak aboveground biomass, but were not linked to changes in microbial biomass. Researchers observed a shift in community-level microbial physiology. They sampled soil from annual and perennial bioenergy cropping systems on three landscape positions in spring, mid-summer and later summer 2011 and found no effect of landscape position on overall microbial activity and no effect of cropping system or landscape position on microbial biomass. However, they found changes in specific types of microbial activity, yielding communities with greater N retention and greater rates of decomposition of soluble carbon inputs from plants.

Greater root inputs and higher enzyme activity under switchgrass were coupled with lower decomposition rates of overall root biomass due to the greater C, N and C:N inputs. The greater inputs of both soluble and resistant C inputs from switchgrass roots created conditions amenable to increased aggregate formation, which can physically protect C as well as enhance soil structure.

Graduate student Sarah Hargreaves uses sterile techniques to collect soil samples from switchgrass plots in the summit position. Samples were used for microbial biomass and activity measurements to understand how crops affect soil carbon and nitrogen retention.

Conclusions

Overall, this research demonstrates that perennial cropping system can enhance plant-microbe interactions, resulting in a greater capacity for improved soil quality on working farms. In combination, research results indicate that through increased root productivity, slower decomposition and enhanced soil aggregation, switchgrass has greater ability than corn to promote soil organic matter formation and soil C storage. The data demonstrate that these differences are driven by augmented root inputs in the switchgrass system, which enhances microbial enzyme activity, resulting in greater soil aggregation, which ultimately supports the potential for greater overall soil C storage.

Impact of results

These results fill an important gap in our understanding of how microbes interact with crops and landscape position to influence soil C storage. This study demonstrates that at the local scale, cropping systems are stronger drivers of soil organic matter formation than landscape position. By increasing root biomass and stimulating microbial activity, perennial systems promote soil aggregation and provide greater carbon and nitrogen retention. Landscape position was less important in this four-year experiment. This may be due to minimal variation in soil properties along the landscape gradient. As a result, root production in annual systems was low in all landscape positions, while perennial root production was generally larger even along marginal soils in the toeslope or backslope positions.

This new understanding of plant-microbe interactions that regulate the partitioning between microbial respiration and SOM formation enables assessment of the C storage value of alternative biomass cropping systems. This work provides new knowledge about plant-microbe-landscape interactions that can inform conceptual and even mathematical models of C storage and cycling in agroecosystems. This work quantifies the benefits of alternative biomass cropping system-landscape combinations, including improved soil quality via increased root biomass, organic matter, and C storage. This information has been used to educate students and land managers.

The specific benefits of the project include: 1) improved understanding of the impact of biomass cropping system and landscape position on plant-microbe interactions that regulate C cycling; 2) improved understanding of how different cropping systems affect C storage; 3) an integrated understanding of how belowground processes regulate C storage that is essential for accurately assessing the C storage potential of various management practices; and 4) dissemination of results to a broad audience of stakeholders.

Education and outreach

Publications

- Hargreaves SK, Hofmockel KS, 2014. Physiological shifts in the microbial community drive changes in enzyme activity in a perennial agroecosystem. *Biogeochemistry* 117:67-79.
- Ontl TA, Hofmockel KS, Cambardella CA, Schulte L, Kolka RK. 2013. Soil impacts on root productivity of bioenergy cropping systems *New Phytologist* 3:727-737.

- Hargreaves SK, Roberto A, Hofmockel KS, 2013. Reaction--and sample--specific inhibition affect standardization of qPCR assays of soil bacterial communities. *Soil Biology & Biochemistry* 59:89-97.
- Three other journal articles are being prepared for publication.

Presentations

- Poster at Soil Science Society of America Meeting National Research Symposium Contest, Cincinnati, Ohio
- Oral presentation and poster showing at annual meeting of the Ecological Society of America annual meeting, Portland, Oregon
- Poster presented at the International Society for Microbial Ecology Symposium,
- Copenhagen, Denmark
- Invited oral presentation at the Scaling Root Processes Global Impacts Workshop, U.S. Department of Energy, Arlington, Virginia
- Three presentations at meeting of the Ecological Society of America, Austin, TX
- Midwest Ecology and Evolution conference, Ames, Iowa
- American Geophysical Union Fall Meeting, San Francisco, California
- Two presentations at the 25th Annual Symposium of the U.S. Regional International Association for Landscape Ecology, Athens, Georgia
- The team also made numerous appearances at various ISU conferences and field days.

Leveraged funds

The team received a grant from to the USDA Agricultural and Food Research Initiative's Managed Ecosystems Grants Program to add a greenhouse gas emissions segment to the project.

Other funds that have been leveraged in support of the project include *approximately*:

- $52,000 in a ISU Plant Sciences Fellowship to Ph.D. candidate Todd Ontl from 2008-2012;
- $450 in 300 tree seedlings donated by ArborGen in 2009;
- $9,360 in research assistantship support from ISU CALS Hall Incentive Account for the portion of a research assistantship for Bill Headlee (Ph.D. 2012) in 2009-2010;
- $19,000 in teaching assistantship support from ISU EEOB for Ph.D.candidate Sarah Hargreaves in 2010-11;
- $14,137 in tuition and fee support from the U.S. Army to support Wade Welsh (M.S. 2011), plus salary in 2010-11;
- $54,000 in 27,000 in teaching and research assistant support from ISU Agronomy to Joshua Henik (M.S. 2012) in 2010-12;
- $19,500 in teaching and research assistantship support from ISU NREM for Ph.D. candidate Todd Ontl in 2011-12;
- $19,500 plus benefits and tuition from ISU Environmental Science for M.S. student Alison King in 2012-13;
- $39,000 plus benefits and tuition from ISU NREM for Usman Anwar in 2012-14;
- $75,000 plus benefits from ISU Agronomy for Research Associate Nic Boersma to provide coordination support for the project between for 2012-15; and
- $5,000 in research support in terms of sample analysis from the U.S. Forest Service Northern Research Station in 2012.

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