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Understanding soil organic matter change: Modeling root and soil interactions across agricultural landscapes

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Abstract
What are some options for enhancing organic content and carbon storage in soils that have been used in intensive row-crop production? The project looked at bioenergy feedstocks and how they might be employed to improve soil properties.

Keywords
Natural Resource Ecology and Management, Farming systems, Soils and agronomy

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ECOLOGY

Q What are some options for enhancing organic matter content and carbon storage in soils that have been used in intensive row-crop production?

A The results showed that despite no change in total soil carbon, all three bioenergy cropping systems studied improved soil structure and increased the protected forms of soil carbon that result in storage of soil carbon. The greatest improvement to soil structure and organic matter levels occurred under switchgrass—likely due to the large amount of root biomass associated with this crop—while continuous corn showed the smallest changes. Additional analyses revealed that soil properties influenced shifts in protected forms of soil carbon through impacts to soil structure and root biomass.

Background

Soil organic matter (SOM) is critical for healthy agricultural lands that provide clean water, clean air and fertile soils. However, decades of intensive use of many agricultural areas have reduced SOM levels and significantly decreased these vital benefits, including soil carbon (C) storage that helps mitigate rising atmospheric CO_2 levels. Emerging markets for cellulosic bioenergy feedstocks provide opportunities for implementing soil conservation practices that restore soil C storage within agricultural landscapes. Soil conservation strategies—including conversion to no-till, use of cover crops, and establishing perennial vegetation—alter belowground C cycling processes and increase soil C storage through protection of SOM. In particular, marginal sites less suited for conventionally tilled annual row-crops are being targeted as appropriate locations for conversion to perennial bioenergy crops. However, the effects of topography and variations in soil properties on belowground C cycling processes remain largely unknown.

The goal of this research was to quantify impacts of variation in topography and soil conditions on short-term changes to soil C under bioenergy crops. Specifically, the researchers sought to understand how plant roots and soil interact to improve the physical structure of the soil through the formation of soil aggregates that protect SOM from further decomposition, ultimately storing more C within soils.

Approach and methods

The proposed work was part of the Landscape Biomass Project (www.nrem.iastate.edu/landscapebiomass) established at the Uthe Farm, an ISU Research and Demonstration Farm located 15 miles southwest of Ames, Iowa. The site was in conventionally tilled corn-soybean rotation for many decades until the establishment of biomass cropping systems began in fall 2008.

The research design consisted of a randomized, replicated experiment comparing five biomass energy cropping systems across five landscape positions: summit, shoulder, backslope, toeslope, and floodplain. All treatments were replicated three times and managed as no-till. Plots are 18 m by 24 m (0.04 ha) with a minimum 6 m buffer between plots. All plots were instrumented with two soil moisture access tubes to 120 cm depth for monitoring soil moisture. Continuous soil and air temperature information was collected on all plots included in this project by using data loggers during the growing season.

Results and discussion

The studies used three bioenergy cropping systems (switchgrass, continuous corn, and a triticale/sorghum double crop). Cropping systems were replicated across five landscape positions along a topographic gradient that includes areas considered to be marginal due to steep slopes or frequent flooding. Measurement of annual root growth of cropping systems showed the highest productivity in switchgrass, while continuous corn was the lowest. Annual cropping systems showed no response to topography or soil properties. Switchgrass productivity was lowest on the floodplain and increased with higher soil sand content, suggesting model predictions of root production may be improved by incorporating information on soil texture. Over three years of study, soil aggregation increased in all cropping systems, although gains were highest under switchgrass. Cropping system effects on aggregation differed among landscape positions.

Although the total amount of C within soil did not change over the three years of this study, organic matter protected within soil aggregates increased, with gains in protected C highest under switchgrass. These results indicate that adoption of no-till, and particularly the conversion to perennial switchgrass, increases forms of stored C. Modeling of C cycling processes revealed that differences in soil properties, particularly soil texture, influenced both root biomass and changes in soil aggregation over time, which then affected the gains in protected forms of soil C during the three years of this study. Contrary to previous studies indicating the primary importance of roots and root-associated microbes for changes in soil aggregation and SOM, these results indicate that soil properties such as soil texture are the main influence for changes in protected forms of soil C in landscapes, even in marginal landscape areas. Further testing across diverse soil and climatic conditions is needed to determine how representative these results are for other agricultural landscapes. However, in areas with more uniform soil conditions across agricultural landscapes, it is likely that increasing root biomass through the production of perennial feedstocks such as switchgrass may have the greatest impact on soil C storage.

Conclusions

The results from these studies emphasize the importance of tillage practices and land use for the expectations of changes in soil C that may result from bioenergy production. Overall, there was a positive impact on stored forms of soil C across all cropping systems, despite no significant change in total C stocks. This is a strong indication of shifts from unprotected organic matter to protected organic matter as soil structure improves and suggests that the cessation of tillage can have positive impacts on C storage in as few as three years. The transfer of C to stored SOM pools was significantly greater under switchgrass, indicating that this benefit can be enhanced with the use of perennial crops, while still providing a biomass harvest. Enhanced transfer of soil C to stored pools under switchgrass was related to greater root biomass, while increases in the unprotected soil C pool were influenced by the high rates of root C inputs to the soil. As aggregation is expected to continue to increase over time under switchgrass, this unprotected soil C pool may boost soil C storage rates even higher.

These results highlight the potential importance of soil conditions on the expectations of soil C storage rates from bioenergy cropping systems, although further testing needs to be done to determine how generalizable these results are across areas with diverse soil conditions. In particular, structural equation modeling (SEM) results suggested the soil property with the strongest influence on aggregation change was soil texture, with higher sand contents leading to both lower aggregation changes and less positive change in stored soil C. In sum, these results suggest that "marginal' soils can store significant amounts of soil C in a short period of time, particularly following conversion from conventionally-tilled annual cropping systems to a perennial system such as switchgrass, but that the expectations of soil C increases may be dependent on the soil properties such as texture. Much recent work has shown that the activity of soil microbes is paramount in understanding C cycling processes. Further SEM analyses of causal networks of soil C pool changes have integrated data on enzyme activities of soil microbes connected in conjunction with this project. (http://link.springer.com/article/10.1007/s10533-013-9893-6)

These analyses have shown novel results that link soil properties, root biomass and microbial enzyme activities with changes in aggregation and stored C pools. (https://www.soils.org/files/am/ecosystems/ontl-poster.pdf)

Impact of results

The objectives of this project were fully achieved to the extent possible within the Landscape Biomass Project experimental design. Results indicate that stored soil C pools changed in just three years, despite no overall changes in soil C stocks. These changes were shown to be related to increases in soil aggregation, which the model suggested was impacted by soil properties such as texture and by root biomass of the various cropping systems included in the study.

The results generated by this project will affect Iowa agriculture on several levels. First, by demonstrating that analyses of total soil C stocks--typically the metric used when determining SOM stocks--may not tell the full story when considering improving SOM and all the benefits derived from soil C. Soil C stocks change slowly over time, but the results from this project show that transfer of soil C to stored pools, necessary for long-term gains in soil C stocks, can occur in just three years.

Second, these results support previous studies showing conversion to no-till management can lead to soil C storage, but furthermore that perennial bioenergy cropping systems such as switchgrass can enhance those benefits.

Finally, the results suggest that soil conditions that typically vary across agroecosystems can play a significant role in impacting gains in stored soil C. The results highlight the importance of both farmers' knowledge of the land, and simple soil analyses of the physical and chemical characteristics of those lands, for informing expectation of soil C storage rates.

Education and outreach

One peer-reviewed scientific article was published in the journal *New Phytologist* (http://onlinelibrary.wiley.com/doi/10.1111/nph.12302/abstract) and one peer-reviewed article was published in the online journal *Nature Knowledge Education* (http://www.nature.com/scitable/knowledge/library/soil-carbon-storage-84223790).

Two other articles are being prepared for submission to scholarly journals. A Ph.D. dissertation (Ontl 2013) based on this work supported by the Leopold Center has been completed.

Outreach activities to the broader scientific community included one poster and oral presentations at four conferences:

- Ontl TA, SK Hargreaves, CA Cambardella, LA Schulte, RK Kolka. 2014. Soil texture and root biomass influence carbon storage through impacts on microbial enzyme activities across a heterogeneous agroecosystem. Soil's Role in Restoring EcosystemServices Conference, Soil Science Society of America Society, March (poster).
- Ontl, TA, CA Cambardella, KS Hofmockel, LA Schulte, RK Kolka. 2013. Spatial variability of soil carbon storage and root productivity in conventional and perennialagroecosystems. Ecological Society of America Annual Meeting, Minneapolis, Minnesota, August (invited oral).
- Ontl, TA, LA Schulte, GLD Larsen. 2013. Bioenergy, biodiversity...or both? (ESA Ignite session) Ecological Society of America Annual Meeting, Minneapolis, Minnesota, August (invited oral).
- Ontl, TA, KS Hofmockel, CA Cambardella , LA Schulte , RK Kolka. 2012. Root dynamics of bioenergy crops: Scaling from the field to landscapes. Ecological Society of America Annual Meeting, Portland, Oregon, August. (oral)
- Ontl, TA, KS Hofmockel, B Sigmon, CA Cambardella , LA Schulte , RK Kolka. 2012. Root contributions to soil organic matter pools: Scaling from the field to landscapes. Scaling Root Processes: Global Impacts Workshop. U.S. Department of Energy, Arlington, Virginia, March. (oral)

Outreach efforts to stakeholders included presentations to the Landscape Biomass project Farmer Advisory Board group at annual meetings in 2011 and 2012. Todd Ontl has presented findings from this research to groups including the Iowa Water and Soil Conservation District Commissioners, and participated as a volunteer for the ISU Extension "Right Practice, Right Place" exhibit at the Iowa Farm Progress Show, August 2013.

Leveraged funds

This grant augmented funds received from a USDA Agriculture and Food Research Institute grant (total funds received: $499,250) to Tom Isenhart and others, titled "Influence of alternative biomass cropping systems on short-term ecosystem processes." Additionally, this grant helped leverage a grant ($12,120 total received) to Lisa Schulte and others from the USDA Forest Service Northern Research Station on "Landscape influences on water quality across biomass cropping systems"

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