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Impacts of Contrasting Rotation Systems and Weed Management Regimes on Weed Dynamics and Agroecosystem Health.

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Abstract

Balancing productivity, profitability, and environmental health is a key challenge for agricultural sustainability. Most crop production systems in the United States are characterized by low species and management diversity, high use of agrichemicals, and large negative impacts on the environment. We hypothesized that cropping system diversification could allow for large reductions in synthetic external inputs used to maintain crop productivity, including herbicides used for weed control. To test this, we conducted a field study from 2008-2016 in central Iowa that included three contrasting rotation systems: a 2-year corn-soybean system, a 3-year corn-soybean-oat with red clover system, and a 4-year corn soybean- oat with alfalfa-alfalfa system. Each rotation system was managed with conventional and low herbicide regimes.

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Project XP2015-02
Impacts of Contrasting Rotation Systems and Weed Management Regimes on Weed Dynamics and Agroecosystem Health

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Keywords
Crop rotation, weed management, life cycle assessment

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Summary for Project XP2015-02

Title: Impacts of Contrasting Rotation Systems and Weed Management Regimes on Weed Dynamics and Agroecosystem Health

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Balancing productivity, profitability, and environmental health is a key challenge for agricultural sustainability. Most crop production systems in the United States are characterized by low species and management diversity, high use of agrichemicals, and large negative impacts on the environment. We hypothesized that cropping system diversification could allow for large reductions in synthetic external inputs used to maintain crop productivity, including herbicides used for weed control. To test this, we conducted a field study from 2008-2016 in central Iowa that included three contrasting rotation systems: a 2-year corn-soybean system, a 3-year corn-soybean-oat with red clover system, and a 4-year corn-soybean-oat with alfalfa-alfalfa system. Each rotation system was managed with conventional and low herbicide regimes.

Herbicide inputs in the 3-year and 4-year systems were 33% and 50% lower, respectively, compared with the 2-year system, and, averaged over rotations, the low regime received 88% less herbicide than the conventional regime. For both corn and soybean, weed dry matter production was greatest for the 3-year rotation managed with the low herbicide regime, averaging 94 kg ha^{-1}; for all other treatments, mean weed biomass production was less than 27 kg ha^{-1}.

Corn yield averaged 4% higher ($p<0.01$) and soybean yield averaged 25% higher ($p<0.001$) in the more diverse systems compared with the 2-year system. Net returns to land and management during 2008–2016 were unaffected by rotation system ($p=0.54$) or herbicide regime ($p=0.69$), with a mean value over years and treatments of \$857 ha^{-1} $year^{-1}$.

Herbicide-related freshwater toxicity loads during 2008-2015, estimated using the USEtox 2.0 model, decreased up to 50% as rotation length increased ($p<0.001$), and were 94% lower with the low herbicide regime than with the conventional regime ($p<0.001$). Soil erosion and P and N discharges in runoff water, estimated using the ArcSWAT model, were unaffected by herbicide regime, but were reduced up to 35% ($p<0.01$), 39% ($p<0.01$), and 60% ($p<0.001$), respectively, by cropping system diversification. Life cycle assessment models indicated that fossil energy use, emissions of greenhouse gases (carbon dioxide, nitrous oxide, and methane), and emissions of various air pollutants (volatile organic compounds, sulfur oxides (SOx), nitrogen oxides (NOx), ammonia, and particulate matter smaller than 2.5 micrometers (PM2.5)) were all reduced significantly ($p<0.001$) as rotation length increased, but were unaffected by herbicide regime. Estimated damage to human health due to air pollutant emissions was \$677/ha/year, \$297/ha/year, and \$226/ha/year in the 2-year, 3-year and 4-year rotations, respectively ($p<0.001$), but was unaffected by herbicide regime.

Taken together, results of this long-term study indicate that diversification of conventional corn-soybean systems can allow for large reductions in the use of herbicides and lead to less environmental and human health damage, higher crop productivity, and equivalent profitability.

Introduction

One of the key challenges for agriculture in the 21st century is the development of weed management strategies that are better able to protect agroecosystem productivity and health. Widespread problems related to herbicide resistance in an increasing number of weed species and environmental contamination by commonly used herbicides indicate the need for diversified management strategies that provide durable weed suppression and effective environmental protection.

This project addressed both of those objectives with the collection of empirical data from a long-term field experiment and modeling analyses. A long-term, 9-hectare (22-acre) experiment established in 2002 at the Iowa State University Marsden Farm was used to compare the agronomic, economic, and environmental performance characteristics of three contrasting rotation systems: a conventional 2-year rotation (corn-soybean) and two more diverse systems: 3-year (corn-soybean-oat + red clover) and 4-year (corn-soybean-oat + alfalfa-alfalfa) rotations that periodically receive cattle manure. Beginning in 2008, sub-plots were created so that each rotation system was managed with two herbicide regimes (conventional and low). Corn and soybean crops managed with the conventional herbicide regime were treated with broadcast applications of preemergence and post emergence products, whereas in the low herbicide regime, they received banded applications of herbicides and interrow cultivation. Oat, red clover, and alfalfa crops sown in the 3-year and 4-year rotations were not treated with herbicides.

In addition to quantifying the effects of rotation systems and herbicide regimes on crop yields, weed infestation, production costs and net returns, this project conducted Life Cycle Assessment (LCA) analyses to evaluate how different rotation systems and herbicide regimes affected fossil energy inputs, greenhouse gas emissions, air pollutant emission, soil erosion, eutrophication via nitrogen and phosphorus discharges, and herbicide-related aquatic ecotoxicity. Dr. Jason Hill of the University of Minnesota led the LCA analyses. The Iowa State University-University of Minnesota partnership facilitated by Leopold Center funding constituted one of the first applications of LCA techniques to contrasting crop and weed management strategies in the U.S. Economic analyses of the contrasting rotation system and herbicide regimes were conducted by Ms. Ann Johanns, Iowa State University Extension and Outreach, with funding from a USDA-NIFA grant. As with the LCA component, Leopold Center funds were used to gather the field data that made her economic analyses possible.

Project design, methods, and materials

Empirical measurements were made at Iowa State University's Marsden Farm, which is situated in Boone County, Iowa (42°01'N, 93°47'W). All soil types at the experimental site are Mollisols. The site has a small amount of sub-surface tile drainage, but it is subject to localized flooding during periods of high precipitation.

Experimental treatments were established in 2002. Preceding set-up of the experiment, the site was used for corn and soybean production for at least 20 years using conventional management practices. Experiment plots were organized in a randomized complete block design, with four replicates of each crop phase of each rotation system present every year. Main plots, each 18 m × 85 m, comprised three different crop rotation systems. Starting in 2008, each main plot was split into two herbicide regimes, each applied over 9 m × 85 m subplots, generating a 3 × 2 factorial set of treatments (Hunt et al. 2017). Plots were managed with conventional farm machinery.

Three crop rotation systems appropriate for the Midwest US were incorporated in this study: a 2-year corn and soybean rotation, and two more diverse systems: a 3-year corn-soybean-oat/red clover rotation and a 4-year corn-soybean-oat/alfalfa-alfalfa rotation. The 3-year rotation system consisted of planting oat with red clover following the soybean crop phase; oat grain and straw were harvested in mid-summer, oat stubble was mowed for weed control, and red clover grew in the stubble until it was incorporated with a moldboard plow in the late fall. The 4-year rotation system consisted of planting oat with alfalfa following the soybean crop phase; oat grain and straw were harvested in mid-summer, oat stubble was mowed once, and the alfalfa was left to grow into the fourth crop phase, when it was harvested three or four times, before being moldboard plowed in the late fall of the fourth year. The more diverse cropping systems were representative of integrated farms that incorporate livestock through forage production and manure recycling. Synthetic fertilizers were applied to corn in the 2-year system at conventional rates based on soil tests. Composted cattle manure was applied in the fall prior to the corn phase, and reduced rates of synthetic fertilizers were applied to corn in the 3- and 4-year rotations (Hunt et al. 2019).

Alternative herbicide application regimes were applied to the corn and soybean crop phases within each rotation system. We implemented a conventional treatment (CONV) comprising broadcast applications of pre- and post-emergence materials and a low-herbicide regime (LOW) involving post-emergence banded herbicide application followed by one or two passes with an interrow cultivator. Herbicide selection was driven by the identity, size, and density of observed weed species. Consequently, herbicide products applied differed among years and herbicide regimes (Hunt et al. 2017). Oat stubble in the 3- and 4-year systems was mowed to suppress weeds 19 to 28 days after grain harvest. Repeated cutting of alfalfa hay suppressed weeds in the alfalfa crop grown in the 4-year system.

Tillage practices varied among rotation systems. The 2-year rotation was chisel-plowed in the fall following corn harvest, and surface cultivated in the spring following soybean harvest. Similar practices were used following corn and soybean phases of the 3- and 4-year systems, but, additionally, soybean residue was disked before planting oat and red clover or oat and alfalfa, and red clover and alfalfa were moldboard plowed in the fall preceding corn production. The effects of these tillage practices were intertwined with those of the crop rotation systems in which they were used, and were part of system-level comparisons in which suites of farming practices varied across the different rotation systems and herbicide regimes.

Harvested crop biomass during 2008–2016 consisted of corn grain yields, soybean yields, oat grain and straw yields, and alfalfa hay yields. Six rows of each corn and soybean subplot, each constituting 382 m^2, were harvested using a combine equipped with a yield monitor. Oat grain was also harvested with a combine having a yield monitor, though measurements were taken over the whole plot area (1,528 m^2). Oat straw and alfalfa were each mowed and baled from the 1,528 m^2 oat and alfalfa plots; alfalfa was harvested three to five times per year following establishment with oat. Aboveground weed biomass from corn and soybean plots was determined in each herbicide regime subplot each year prior to crop harvest based on eight randomly selected 3.05 m × 0.76 m sampling areas. Weed biomass samples were placed in forced air ovens for drying, then weighed at ~0% moisture content. Densities of viable weed seeds in the soil to a depth of 20 cm were determined from thirty-six 19-mm-diameter soil cores drawn from each plot after crop harvests were completed in 2014-2016. Seeds were separated from soil with water using an elutriator (Wiles et al. 1996) and were enumerated by species and analyzed for viability using direct germination and crush testing (Borza et al. 2007).

Economic returns to land and management were calculated at experimental unit level for each rotation system and herbicide treatment using field operations logs for labor demands, seed and chemical inputs, crop yields, and year- and product-specific databases for materials costs, operations costs, and crop prices. Input costs included seeds, fertilizers, and herbicide products, and were obtained from local retailers and Iowa and Midwest-based reports. Labor, fuel, and machinery cost data were derived from Iowa State University Extension and Outreach publications. Costs associated with manure application in the 3- and 4-year rotation systems assumed that manure was produced by on-farm or neighboring-farm livestock with the costs of labor and machinery required for application; no cost was assigned to the manure itself, which was assumed to be a waste product from the livestock enterprise. This approach is appropriate with the caveat that if crop farmers purchased manure, net returns would be reduced (Poffenbarger et al. 2017). Iowa market year crop prices were obtained from the USDA National Agricultural Statistics Service, and gross revenue was calculated as the product of crop price and yield. Costs and revenue from mortgage, lease, and government payments were excluded from the study. Net returns to land and management were calculated as the difference between gross returns and non-land and non-marketing costs. Information sources and calculations of net returns to land and management are described in detail in Hunt et al. (2017) and Hunt et al. (2019).

Herbicide toxicity to aquatic organisms was assessed using the USEtox 2.0 model and procedures detailed by Hunt et al. (2017). Nitrate-nitrogen leaching, nitrogen and phosphorus discharges in overland flow ('run-off'), and soil erosion were estimated using the ArcSWAT hydrologic process model and procedures described by Hunt et al. (2019). Fossil energy use, emissions of greenhouse gases (carbon dioxide, methane, nitrous oxide), and emissions of all air pollutants other than ammonia were estimated using the GREET model (https://greet.es.anl.gov). Ammonia emissions were calculated using values from scientific literature and the National Emissions Inventory (https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei). The InMAP model was used to estimate damage to human health from air pollutants (Tessum et al. 2017).

Data were analyzed with linear mixed effect models that treated rotation system and herbicide as fixed factors and replicate block and year as random factors.

Key results

Herbicide inputs in the 3-year and 4-year systems were 33% and 50% lower, respectively, compared with the 2-year system, and averaged over rotations, the low-herbicide regime received 88% less herbicide than the conventional regime. Dominant weed species in the experiment were common waterhemp (*Amaranthus rudis*), common lambsquarters (*Chenopodium album*), giant foxtail (*Setaria faberi*), yellow foxtail (*Setaria lutescens*), and dandelion (*Taraxacum officinale*). In general, for both corn and soybean, weed dry matter production was greatest for the 3-year rotation managed with the low herbicide regime, averaging 94 kg ha^{-1}; for all other treatments, mean weed biomass production was below 27 kg ha^{-1} (Hunt et al. 2019). For corn, there was no difference between herbicide regimes in the 2-year system ($p=0.50$), whereas weed biomass was greater with the low regime than the conventional regime in the 3-year ($p=0.01$) and 4-year ($p=0.04$) systems. For soybean, weed biomass was greater in the low than in the conventional herbicide regime in the 3-year rotation ($p<0.001$) and 2-year rotation ($p<0.05$), but did not differ between herbicide regimes in the 4-year system ($p=0.15$). In 2014-2016, weed seed density in the soil did not differ between herbicide regimes ($p=0.17$), but was strongly affected by rotation system ($p<0.01$). Weed seed densities were highest in the 3-year rotation, lowest in the 2-year rotation, and intermediate in the 4-year rotation.

During 2008-2016, corn yield averaged 4% higher ($p<0.01$) and soybean yield averaged 25% higher ($p<0.001$) in the more diverse systems compared with the 2-year system (Hunt et al. 2019). An economic analysis conducted with data from 2008-2016 indicated that increases in rotation length led to greater labor requirements and decreased gross revenue (Hunt et al. 2019). However, production costs also dropped substantially as cropping system diversity increased. Net returns to land and management during 2008–2016 were unaffected by rotation system ($p=0.54$) or herbicide regime ($p=0.69$), with a mean value over years and treatments of \$857 ha^{-1} $year^{-1}$ (Hunt et al. 2019).

Freshwater toxicity loads during 2008-2015 were estimated using USEtox 2.0, a consensus model that incorporates active ingredient-specific aquatic species toxicity, physiochemical properties, and degradation characteristics. For the conventional herbicide regime, ecotoxicity per unit of land area decreased up to 50% as rotation length increased ($p<0.001$), whereas for the low herbicide regime, no difference was detected among rotation systems ($p=0.60$) (Hunt et al. 2017). Averaged over rotation systems, the annual average freshwater toxicity load of the conventional herbicide regime per hectare was approximately nine times greater than that of the low regime (Hunt et al. 2017).

Soil erosion and nitrogen and phosphorus discharges during 2008-2016 were estimated using the hydrologic process model ArcSWAT. Herbicide regime had no effect on soil erosion or nutrient discharges (Hunt et al. 2019). In contrast, increasing cropping system diversity by adding oat and forage legumes to the 2-year corn-soybean rotation reduced total P and N loss in run-off up to 35% ($p<0.01$) and 39% ($p<0.01$), respectively, though it had no significant effect on NO_3-N loss through leaching ($p=0.75$) (Hunt et al. 2019). Estimated erosion losses were reduced up to 60% through cropping system diversification ($p<0.001$) (Hunt et al. 2019).

Life cycle assessment models indicated that fossil energy use, emissions of greenhouse gases (carbon dioxide, nitrous oxide, and methane), and emissions of various air pollutants (volatile organic compounds, sulfur oxides (SOx), nitrogen oxides (NOx), ammonia, and particulate matter smaller than 2.5 micrometers (PM2.5)) were all reduced significantly ($p<0.001$) as rotation length increased, but were unaffected by herbicide regime. Estimated damage to human health due to air pollutant emissions was \$677/ha/year, \$297/ha/year, and \$226/ha/year in the 2-year, 3-year and 4-year rotations, respectively ($p<0.001$), but was unaffected by herbicide regime.

Conclusions

Taken together, results of this long-term study indicate that diversification of conventional corn-soybean systems with small grains and forage legumes, coupled with the integration of livestock production, can allow for large reductions in the use of herbicides and lead to less damage to human health and the environment, higher crop productivity, and equivalent profitability. Thus, the diversified, integrated crop-livestock systems we have investigated are in many ways more sustainable than a conventionally managed corn-soybean rotation. Translating these potential gains in agricultural sustainability into broad-scale changes in the U.S. Corn Belt will likely depend on combinations of factors that include government policies, farmer confidence, technical support, and markets for ‘non-conventional’ products.

Reference citations

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Outreach

As part of my on-going outreach and extension activities, I presented information about this project to farmers, agricultural professionals, and research scientists at multiple locations. Presentations were given at the following venues:

Practical Farmers of Iowa, Rotationally Raised: Making Small Grains Work conference, Mankato, MN (30 July 2018). Two presentations: Weed control with and for small grains; Cropping system diversity–effects on production, soil health, and profitability.

University of Minnesota, organic field day, Southwest Research and Outreach Center, Lamberton, MN (11 July 2018). Cropping system diversity–effects on production, soil health and profitability.

American Society of Agronomy, Sustainable Agronomy Conference, Madison, WI (26 June 2018). Ecologically based weed management: principles and practices.

University of Maine, webinar for undergraduate cropping systems class, Orono, ME (5 March 2018). Enhancing biodiversity in the Corn Belt to improve environmental quality and crop production.

Raccoon River Watershed Association, Life in the Raccoon River conference, Perry, IA (3 March 2018). Agricultural sustainability and resilience: principles and practices.

Southeast Iowa Agricultural Research Association and Iowa State University Extension and Outreach, annual meeting, Iowa City, IA (1 March 2018). Cropping system diversity: effects on production, soil health, and profitability.

Midwest Organic and Sustainable Education Service, Organic University short course, La Crosse, WI (22 February 2018). Ecological weed management.

University of Wisconsin-Madison, Organic Grain Resource and Information Network (OGRAIN), 2018 winter conference, Madison, WI (27 January 2018). Ecologically based weed management.

American Society of Agronomy–Soil Science Society of America, education webinar for Cultivating Sustainability: A Training Curriculum for Agronomy (8 November 2017). What is sustainability?

Soil and Water Conservation Society, 72nd international annual conference, Madison, WI (31 July 2017). Effects of increased crop rotation diversity in Iowa on weed control, aquatic toxicity, and economics.

Iowa Academy of Science, 129th annual meeting, Cedar Falls, IA (21 April 2017). Cropping system diversification strategies for enhanced performance and greater resilience: two case studies.

Department of Plant Sciences, Dan Hess Endowed Weed Science Seminar, University of California–Davis, Davis, CA (12 April 2017). Cropping system diversification in the U.S. Corn Belt for enhanced performance and resilience.

Berkeley Food Institute, University of California–Berkeley, Berkeley, CA (10 April 2017). Enhancing biodiversity in the Corn Belt to improve environmental quality and crop production.

Senator George J. Mitchell Center for Sustainability Solutions, University of Maine, Orono, ME (27 March 2017). Enhancing biodiversity in the Corn Belt to improve environmental quality and crop production.

Midwest Organic and Sustainable Education Service, Organic Farming Conference, La Crosse, WI (23 February 2017). Effective weed management.

Iowa State University Outreach and Extension, Soil Health Conference, Ames, IA (17 February 2017). Organic amendments and cropping system diversification as management approaches for improving soil health.

Practical Farmers of Iowa, annual conference, Ames, IA (21 January 2017). Managing weeds more successfully.

Iowa State University Extension and Outreach and USDA Natural Resources Conservation Service, 2016 Western Iowa no-till field day, Shelby, IA (21 June 2016). Benefits of diversifying corn-soybean systems.

Practical Farmers of Iowa, Lehman Farm field day, Polk City, IA (20 June 2016). Reintegrating small grains into crop rotation systems.

Iowa Learning Farms, Johnson County Soil and Water Conservation District, and Iowa Soybean Association, cover crop and soil health field day, Solon, IA (16 June 2016). Benefits of multi-crop rotation systems.

Iowa Renaissance Weekend XXIII, Grinnell, IA (16 April 2016). Diversified cropping systems for soil and water protection.

Taylor County Soil and Water Conservation District, 2016 Soil Health Conference, Lenox, IA (23 February 2016). Some benefits of multi-crop rotation systems.

Gulf of Mexico Oil Spill and Ecosystem Science Conference, Tampa, FL (2 February 2016). Diversified cropping practices in the U.S. Corn Belt for water quality protection in the Gulf of Mexico.

Practical Farmers of Iowa, annual conference, Ames, IA (22 January 2016). Using biology and ecology to improve weed management in low input and organic farming systems.

Practical Farmers of Iowa, annual conference, small grains short course, Ames, IA (21 January 2016). Adding oats to a corn-soybean cropping system.

Swedish University of Agricultural Sciences, Uppsala, Sweden (15 January 2016). Cropping system diversification in the U.S. Corn Belt for enhanced performance and resilience.

Entomological Society of America, annual meeting, symposium on ecosystem services and resilient, multifunctional agricultural systems, Minneapolis, MN (17 November 2015). Enhancing agroecosystem performance and resilience through increased diversification of landscapes and cropping systems.

Soil Science Society of America, annual meeting, symposium on long-term agricultural research, Minneapolis, MN (17 November 2015). Agronomic, economic, and environmental performance characteristics of conventional and more diverse cropping systems in the U.S. Corn Belt.

American Society of Agronomy, annual meeting, symposium on management and biological control of weeds in agroecosystems, Minneapolis, MN (17 November 2015). Evaluation of contrasting weed management systems using multiple performance criteria.

University of Minnesota-Twin Cities, Green Lands Blue Waters conference, Minneapolis, MN (3 November 2015). How can we best assess the economic performance of integrated crop-livestock systems?

Virginia Polytechnic Institute and State University, agriculture and the environment seminar series, Blacksburg, VA (1 September 2015). Increasing diversity enhances cropping system performance: results of two field experiments in Iowa.

Green Lands Blue Waters/University of Minnesota, telecast workshop on integrating continuous living cover into farming systems, Northeast Iowa Community College, Calmar, IA (6 August 2015). Continuous living cover in rotations and landscape placement.

Organic and Integrated Pest Management Working Group, phone seminar (4 August 2015). Using simple models to improve weed management in low-external-input and organic farming systems.

Soil and Water Conservation Society, annual conference, symposium on long-term agricultural research, Greensboro, NC (27 July 2015). Agronomic, economic, and environmental performance characteristics of conventional and more diverse cropping systems in the US Corn Belt.

Iowa State University Extension and Outreach, Northeast ISU Research Farm field day, Nashua, IA (24 June 2015). Economics of diversified crop rotations.

University of Iowa, Forkenbrock Series on Public Policy, Symposium: Feeding the World: Challenges for Water Quality and Quantity, Iowa City, IA (9 April 2015). On-farm diversification to protect Iowa's soil, water, and wildlife.

Eastern Iowa Hay Producers Association, annual meeting, Welton, IA (19 March 2015). Performance characteristics of simple and more diverse rotation systems for field crops.

Iowa State University, Department of Plant Pathology and Microbiology, seminar, Ames, IA (27 January 2015). Performance characteristics of simple and more diverse rotation systems for field crops.

Iowa State University Extension and Outreach, Crop Advantage Series, Moravia, IA (15 January 2015). Performance characteristics of diversified crop rotation systems.

Student training and professional development related to the project

Baldwin-Kordick, Rebecca. M.S. in Agronomy (Soil Science), Iowa State University. 2018. Soil health and root-influenced biochemical dynamics in conventional and integrated livestock systems in central Iowa.

Budi, Joshua. M.S. in Plant Pathology and Microbiology and Sustainable Agriculture, Iowa State University. Entered in 2017. (Co-supervised with Dr. Leonor Leandro).

Nguyen, Huong. M.S. in Sustainable Agriculture, Iowa State University. 2016. Reducing herbicide use through cropping system diversification: A case study at the Iowa State University Marsden Farm, and some recommendations for the Mekong Delta of Vietnam. Currently: Ph.D. student in Sustainable Agriculture, Iowa State University, Ames, IA. Entered in 2016.

Nichols, Virginia. Ph.D. in Agronomy (Crop Production and Physiology), Iowa State University. Entered in 2018. (Co-supervised with Dr. Sotirios Archontoulis)

Osterholz, William. Ph.D. in Agronomy (Soil Science) and Sustainable Agriculture, Iowa State University. 2016. Nitrogen pools and fluxes in diversified cropping systems. (Co-supervised with Dr. Michael Castellano). Current position: Post-doctoral scientist, Department of Agronomy, University of Wisconsin–Madison.

Poffenbarger, Hanna. Ph.D. in Agronomy (Soil Science) and Sustainable Agriculture, Iowa State University. 2017. Dissertation: Nitrogen fertilization and crop diversity effects on soil carbon and nitrogen cycling in Iowa cropland. (Co-supervised with Dr. Michael Castellano). Current position: Assistant professor, Department of Plant and Soil Sciences, University of Kentucky.

Rodbell, Erika. M.S. in Entomology and Sustainable Agriculture, Iowa State University. Entered in 2016.

Published articles and book chapters related to the project

Poffenbarger, H.J., D.C. Olk, C. Cambardella, J. Kersey, M. Liebman, A. Mallarino, J. Six, and M.J. Castellano. *In review*. Whole-profile soil organic matter content, composition, and stability under crop rotations differing in belowground inputs in Midwest U.S. Mollisols. **Agriculture, Ecosystems, and Environment**.

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Budget report

The total amount of funds awarded for this project was of $75,650. The original project period was 1 February 2015 to 31 January 2018, but the project was extended until 30 April 2018. Expenditures in Years 1, 2, and 3 were $24,475, $25,209, and $25,966, respectively.

Funds were used primarily for a graduate student stipend, undergraduate student labor, and associated benefits; small amounts of funding were used for soil fertility analyses by a private laboratory, and fees paid to Iowa State University for composted manure, plot rental, and harvest operations.

Complementary extramural funding

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