Final Report for Award No. DE-EE0007088/0000

Enabling Sustainable Landscape Design for Continual Improvement of Operating Bioenergy Supply Systems

Prime Recipient: ANTARES Group Inc.

Subcontractors: FDC Enterprises; USDA-Agricultural Research Service; Pennsylvania State University; Oak Ridge National Laboratory; Idaho National Laboratory; Argonne National Laboratory; AgSolver/EFC Inc.; and DLKarlen Consulting, LLC.

Project Duration: April 1, 2016, through September 30, 2021

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CONTRACTOR: Antares Group Incorporated		**DOE Project Coordinator**	
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Title:	Associate Principal	Title:	Project Director

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Project Background

This unique and highly effective project catalyzed collaboration among government, university, and private sector partners through a multi-state research and technology transfer project designed to support continuous improvement of bioenergy feedstock supply systems. Conceived and built upon the foundation created by prior DOE investments in the Billion Ton Study, Sun Grant Regional Project, and many other feedstock production, harvest, storage and transportation studies, this project addressed seven tasks with more than 29 subtasks. All goals were met with key accomplishments being: (1) on-farm establishment of potential perennial plant mixtures that could not only become sustainable feedstock sources but also enhance soil health, (2) a reduction in potential wind and water erosion by improving corn stover harvest techniques and incorporating cover crops into current row-crop production systems, (3) reduced potential for surface and groundwater contamination while also increasing potential biodiversity and sustainability of Midwestern USA landscapes, and (4) development of site-specific land management, data visualization, and sustainability assessment tools. Twenty-two Case Studies highlighting accomplishments and lessons learned through this public-private partnership investment are incorporated into this final report. On-farm and replicated field plot studies were used to provide the real-world data needed to verify baseline assumptions for extensive feedstock logistic modeling and greenhouse gas (GHG) assessments needed to develop sustainable bioenergy and bio-product industries at national and international scales.

Report Structure

This multi-million-dollar public-private partnership was designed to evaluate the use of landscape design principles for continuous improvement of operating bioenergy supply systems. Numerous scientific, community outreach, and educational accomplishments were achieved by a highly effective team, coordinated by the Antares Group Inc., and having more than 50 scientists and engineers who made significant contributions to the project. Multiple accomplishments and substantial leveraging of DOE resources with funds or in-kind investments were made possible due to the dedication of every team member.

Ten overall conclusions and ten recommendations for future research are presented as outcomes of this investment. Research accomplishment, examples of the leveraging and multi-agency partnerships, and examples of the numerous outreach and technology transfer activities are highlighted in 22 Case Studies. They provide a glimpse of the data, experiences, and outcomes of this DOE funded project that will directly or indirectly affect many different stakeholders who are interested in bioenergy or bio-product development and commercialization. Each contribution associated with this project is envisioned as having great potential to support and further develop global industries needed to address climate change and increasing weather variability, rural development, profitability, energy security, carbon sequestration, and other economic, environmental, and ecosystem service issues.

The report concludes with a list of more than 50 refereed technical publications that document the breadth of investigations conducted by Team members. We feel each will make a strong contribution to the development of coordinated local, regional, national, and even international guidelines for using Landscape Design principles to help address 21st century agricultural economic, environmental, and social challenges. We expect this report to be useful not only for encouraging development of sustainable biofuel and bio-product industries, but also to enhance soil health, water and air quality, rural economic development, and overall quality of life for urban, suburban, and rural communities.

This written report is augmented by a website entitled "Precision Farming for Bio-Energy Production" [https://www.sustainablelandscape.design]. The on-line site presents "Our Story", "Vision", and "Key Strategies" that were evaluated as potential landscape-design soil and crop management practices which could be implemented to support or enhance continuous improvement of bioenergy feedstock supply systems. It also introduces various Analytical Tools created or improved by Team members contributing to this multi-agency public-private project. Several supporting Resources – interviews, presentations, reports and papers, a Photo Gallery, and a listing of Team members are also presented. Our intent for the website is to provide a user-friendly educational tool for further development of Landscape Design scenarios that will enhance profitability for multiple stakeholders, enhance soil health, protect surface- and ground-water resources, help decrease GHG concentrations by sequestering CO_2, and enhance quality of life for rural and urban residents. In summary, our goal was to develop socially, environmentally, and economically sustainable cellulosic bioenergy and bio-product feedstock production practices that will be useful at local, state, national, and international scales.

Outreach and Education Activities

Site Specific Soil Health Reports

A very important and extremely well-received product of this Landscape Design project was the development and dissemination of site-specific soil health reports to each of the 18 farmer cooperators. Project coordinator, Dr. Virginia Jin [USDA-Agricultural Research Service (ARS) Research Leader for the Agroecosystem Management Research Unit in Lincoln, NE] met with every landowner and/or their farm manager as this project component was being designed and implemented. Representative sites (Figure 1) were selected within fields under contract with one of the Landscape Design team members (FDC Enterprises, Inc.). Their role was to establish perennials on fields in central Iowa, USA as a vendor for implementing the CP-38 component of the USDA Conservation Reserve Program (CRP). Multiple ARS team members contributed to site selection, sample collection, analysis for multiple soil health indicators, data analysis, and preparation of the reports. One of the technical publications (LiDong et al., 2021) summarizes these on-farm studies and presents an overview of the soil health data collected to quantify the impact of this landscape design conservation practice.

At each site, soil samples were collected from Conservation Reserve Program (CRP) sites that had been established for at least 10 years, long-term pasture sites, row-crop sites, or row-crop sites that were recently enrolled in the CP-38 pheasant recovery program (one CRP program) and planted to perennial grasses. Soil samples were collected from moderate (7 to 13%) and high (13 to 25%) slope positions within each sampling site.

Each landowner was given a general project overview, description of the sampling and analytical methods used for the assessment, summaries of the biological, chemical, and physical measurement data, an overall soil-health summary, a risk of soil erosion (by wind and water) assessment and copy of the data collected from their sites.

Figure 1. Representative on-farm sites sampled for soil health assessment in central Iowa, USA.

Long-term Pasture

Established CRP

Business as Usual (BAU)
Row Crop site

Newly Established CP-38 land

Private-Sector Contributions

One of the project's collaborating research partners [Fred D. Circle Enterprises Inc. (FDCE)] enhanced the impact of this DOE research and technology development investment by working with more than 300 land managers in Iowa to establish perennial biomass crops. Since there is no current market for cellulosic feedstocks, there is very little incentive for producers to change their production practices. With great creativity and innovation, FDCE and Project Leaders were able to secure approval to enroll the fields into a new CP-38 (pheasant recovery) CRP program. The Landscape Design research team secured USDA-Farm Service Agency (FSA) and Natural Resources Conservation Service (NRCS) approval for using a slightly modified mixture of grass seed that would meet approved protocols for CP-38 and provide acceptable cellulosic feedstock for bioenergy or bio-product industries.

Overall, FDCE partners established 3,000 acres of Liberty switchgrass in Iowa. Eighteen of those sites were then selected as ARS sampling sites for assessing soil health impacts. FDCE also leveraged a 580 acre (235 ha) on-going switchgrass project near Elkton, VA to augment this Landscape Design research project.

This Landscape Design project also enabled several team members to collaborate with Jim Straeter and the New Holland International Corporation to further develop the Straeter Header for sustainable corn stover harvest. This included developing web-enabled, remote-controlled camera technology to accurately monitor stover harvest operations. Those activities provided critical data for simulation modeling for assessing the feasibility and operability of biomass planting, harvest, and logistics for a biorefinery. The collaborative efforts also provide important, practical information for industrial harvesting of switchgrass, corn stover, or other cellulosic feedstocks which can be a complex operation if fields are small or irregular in shape.

Simulation Model Developments and Enhancements

1. Oak Ridge National Laboratory (ORNL) team members contributed to this project by leveraging on-going research associated with the Integrated Biomass Supply Analysis and Logistics (IBSAL 2.0) and Multi-Attribute Decision Support Systems (MADSS) multi-attribute decision support models.

2. ARS team members leverage project resources to continue development, enhancement, and evaluation of the Unified Plant Growth Model (UPGM), Wind Erosion Prediction System (WEPS), Soil Water Assessment Tool (SWAT), Water Erosion Prediction Project (WEPP) and AgroEcoSystem (AgES) models.

3. Pennsylvania State University (PSU) simulation models for the Mahantango Creek Watershed in central PA showed that double cropping with winter rye could increase grain yield, cellulosic feedstock supply, and farm profit by as much as \$404 ha^{-1} yr^{-1}.

4. A random forest analysis (modeling technique) was used to evaluate hydrologic, topographic, and agronomic effects on productivity. Landsat-derived normalized

> difference vegetation index (NDVI) maps provided a proxy for productivity. Seasonal weather and crop type had the largest effect, followed by a topographic wetness index and the area contributing water to each field. Soil profile attributes and use of manure (rather than fertilizer) had minor effects on productivity, assuming our interpretation of the data resulted in an accurate designation of being a manured or non-manured field.

Validation of BMAS

With input from several Team Members, the Biomass Market Access Standard (BMAS) was significantly improved. Designed as a voluntary sustainability standard for cellulosic feedstock production, harvest, storage, and transportation (PHST) processes in support for emerging bioenergy and bio-product industries, BMAS evolved from a Council on Sustainable Biomass Production (CSBP) Standard released in 2012. Using field-scale data provided by this Landscape Design project, a simplified, user-friendly interface was created enabling further testing without requiring hundreds of hours for data collection and entry. BMAS was evaluated by Michael Keyes, an experienced food systems auditor who was familiar with the standard's infancy and history after working with the CSBP to field test the 2012 version.

BMAS was evaluated using FDC Enterprise on-line responses to the Standard's integrated resource management plan (IRMP) for their switchgrass operations in Virginia. It was also evaluated for a corn/soybean operation near Dexter, IA to represent a site where a sustainable amount of corn stover could be harvested. Evaluations for both sites focused on six principals: (1) Soil, Water, and Air Quality, (2) Biodiversity, (3) Socio-economic impact in the Community, (4) Legality, (5) Transparency, and (6) Continuous Improvement. Those six principles were agreed upon by CSBP and, in general, other national and international environmental groups as being essential to certify any land use or management practice as being sustainable.

Upon completion of his evaluation, Keyes stated he was excited and impressed with the level of detail FDC was able to provide about the switchgrass operation production system. Team Leader, Kevin Comer, identified and utilized a commercially available product to gather all soil information, land, water quality, and biodiversity attributes of the FDC production footprint in Virginia. Both sources of BMAS input data exceeded Michael's expectations and subsequently, a commercial product being utilized by companies to develop construction permits in Virginia was modified to meet the needs of agricultural operations for future data collection.

For Belden Family Farms LLC which is operated under a share/lease contract, information held by various organizations was used to respond to the Standard’s questions. USDA/NRCS, Iowa Department of Agriculture and Land Stewardship (IDALS), US Fish and Wildlife Service, and farm management records were used as BMAS input. The Iowa evaluation has not been completed. Belden Family Farms LLC is waiting for additional information from some crop input vendors. This has helped identify a potential challenge for BMAS assessments as some providers questioned if responding could affect their permits, operations, and employee protections. These points are being shared to help guide future sustainability evaluations of cellulosic feedstock PHST.

Field-Day Presentations

Throughout the duration of this project Team Members hosted or contributed to numerous outreach activities associated with various components of Landscape Design. This included sessions on switchgrass production potential on marginal lands; quantifying land use impacts on belowground root inputs; stakeholder meetings on soil health; innovative conservation practices including on-farm catchments, conservation practices for sustainable corn stover harvest and management, saturated buffers; the Agricultural Conservation Planning Framework (ACPF); bioenergy production, water quality, biodiversity impacts, and soil erosion control.

Support for Professional Development

Resources from this Landscape Design project provided educational support for Ph.D. graduate studies and post-doctoral research and technology transfer experiences. Persons supported by this project include:

Graduate Degree Recipients

Veronika Vazhnik, PhD Student, 2016-2020 Penn State
Topic and role: Logistic and supply chain, worked closely with INL team. Conducted on farm interviews in Iowa on sustainability indicators and metrics as well as modeling. Prepared manuscripts for scientific journals and extension bulletins.
Biorenewable Resources at Penn State
Advisor: Tom Richard

Rachel Rozum, PhD Student, 2016-present, Penn State
Topic and role: Modeling land-use management in Iowa, landscape design, hydrology. Worked with ORNL team. Prepared manuscripts for scientific journals and attended scientific conferences.
NSF Graduate Research Fellow
Ecology program at Penn State
Advisor: Armen Kemanian (Plant Science)

Stephanie Herbstritt, PhD Student, 2016 - 2021, Penn State
Topic and role: Switchgrass and other multi-species mixtures for biomass in PA. Also conducted multiple extension activities in Pennsylvania, and prepared manuscripts for scientific journals.
Agricultural and Biological Engineering program at Penn State
Advisor: Tom Richard

Jasmine Kreig, PhD Student 2017-2021, University of Tennessee Bredesen Center - ORNL
Topic and Role (supported by BETO AOP, not the Antares project, but worked closely with the team in the context of this project in a mutually beneficial collaboration). Thesis: Birds and Bioenergy: a modeling framework for managed landscapes at multiple spatial scales.
Supervisor: Henrietta (Yetta) Yager

Post-Doctoral Research Scientists

Mriganka De, 2019 – 2021, Iowa State University (ISU)
Topic and role: Collected root cores and began washing cores for roots in multiple plant communities including perennial grasses and forbs. Dr. De is now a faculty member at the Minnesota State University in Mankato, MN.
Supervisor: Marshall McDaniel

Lidong Li, October 2019 – August 2021, USDA-Agricultural Research Service (ARS)
Topic and Role: Compiled landowner soil health data from CRP and adjacent BAU management; prepared landowner reports; prepared draft soil health case study for final closeout report; prepared manuscripts for submission to peer-reviewed journals. Dr Li will start another postdoc at University of Nebraska Lincoln with Dr. Michael Kaiser to evaluate physico-chemical and biological mechanisms driving soil organic carbon dynamics.
Supervisor: Virginia Jin

E. Britt Moore, 2019 – 2021, ISU
Topic and Role: Completed tasks associated with washing cores for roots in multiple plant communities including perennial grasses and forbs plant root growth in samples from the on-farm CP-38 research sites. Britt is now a faculty member at the University of North Carolina, Wilmington.
Supervisor: Marshall McDaniel

Márcio R. Nunes, 2018 – 2021, USDA-ARS, ORISE Program
Topic and role: Developed expertise with the Soil Management Assessment Framework (SMAF) and applied it to various experiments evaluating the sustainability of soil and crop residue management practices. Marcio published several refereed journal papers, book, chapters, and provided leadership for developing the new Soil Health Assessment Protocol and Evaluation (SHAPE) tool. Currently Márcio is interviewing for several potential faculty positions in the U.S. and Brazil.
Supervisor: Douglas L. Karlen

John F. Obrycki, 2016 – 2018, USDA-ARS, ORISE Program
Topic and role: Quantified management practice effects on soil functions and ways to enhance cellulosic biomass supplies while protecting soil resources. John published ten refereed journal articles, two book chapters, and taught soil health principles to USDA-NRCS and other field scientists and agricultural producers during his tenure with the project. He is now Coordinator for ultra-low temperature sample storage at Harvard University.
Supervisor: Douglas L. Karlen

Bhavna Sharma, 2016 – 2018, Oak Ridge National Laboratory (ORNL)
Topic and role: Logistics analysis in regions with integrated corn stover and switchgrass production to determine optimal supply chain configurations for multi-feedstock delivery. Dr. Currently Sharma is Senior Manager, Merchandising Strategy & Analytics at SHIPT.
Supervisor: Erin Webb

Sabrinna Soldavini, 2016 – 2018, Purdue University
Topic and role: Economic assessments of switchgrass harvest as a cellulosic feedstock.
Currently a Policy Analysist with MCE Clean Energy in Portland, OR.
Supervisor: Wally Tyner

Selected Educational Contributions

A literature review and local stakeholder engagement in Iowa identified five environmental and six socio-economic indicator categories associated with production, harvest, storage, and transport of cellulosic feedstocks.

To ensure development of sustainable cellulosic feedstock supplies, producers must have more than one potential market. Having multiple potential uses for feedstock and co-existing markets will help reduce the risk of supply shortages because agricultural producers can rely on an outlet where their products can be sold, and they can achieve a dependable return on investment (ROI) without government intervention. Potential biomass markets identified through this project include animal feed, bedding or other absorbents, construction materials, erosion control socks, pulp and paper and organic chemicals.

Overall Conclusions

1. Implementing the principles of landscape design can improve operating bioenergy and/or bio-product supply systems because they integrate economic, environmental, and social pillars of sustainability.

2. Landscape design not only enhances bioenergy supply systems, but also can have multiple other benefits including improved or enhanced soil health, increased productivity and profitability, protection of surface- and ground-water resources, mitigation of increasing atmospheric CO_2 concentrations, and enhancement multiple ecosystem services (e.g., wildlife habitat, nutrient cycling, water use efficiency) at field-, farm-, and watershed-scales.

3. There is no single “correct” Landscape Design, diversification strategy, or set of land management practices that will meet all stakeholder goals.

4. Successful implementation of landscape design and similar, complex, multi-stakeholder bioenergy, bio-product, or conservation projects will require formation of effective and collaborative public-private partnerships.

5. Public-private partnerships should strive to represent everyone (i.e., farmers, ranchers, environmentalists, conservationists, researchers, engineers, bioenergy and bio-product industries, investment bankers, individual citizens, or other groups) who may be affected by any landscape or other type of broad-scale change.

6. Leveraging, outreach, and the ultimate success of this DOE investment coupled with USDA and State collaboration illustrate how federal and state government investment can be used to stimulate collaborative public-private partnerships.

7. The on-line website [https://www.sustainablelandscape.design], publications, and Case Studies not only summarize the success and impact of this five-year project, but also provide documentation for subsequent multi-Agency research, development, and outreach projects.

8. Coordinating USDA Natural Resources Conservation Service (NRCS) Conservation Reserve Programs (CRP) such as CP-38, Environmental Quality Incentive Program (EQIP), and Conservation Improvement Grants (CIG) with US-DOE bioenergy programs can be highly effective for ensuring stable feedstock supplies and promoting soil and water conservation across broad agricultural landscapes.

9. Monitoring soil health indicators can be very effective for assessing multiple ecosystem service and Landscape Design effects across broad geographic areas. For example, differences between business as usual (BAU) row-crop and long-term CRP were much larger than differences between BAU-Pasture (BP) and CRP sites.

10. Farmers will implement diversified landscape design and other conservation practices provided there is market demand and economic return for the goods and services they produce. Simply stated, agricultural producers want to care for their land, families, and communities but cannot do so without appropriate financial rewards for their economic risk and labor investments.

Recommendations for Future Projects

1. Public-Private partnerships assembled to design, develop, and implement landscape design or other natural resource conservation practices that bridge mutual interests of urban, suburban, and rural segments of America should include government and non-government partners.

2. Every member of the partnership (e.g., NRCS, FSA, Cooperative Extension personnel; non-government organizations (NGOs); students and teachers; community leaders) should be encouraged to contribute to planning, coordination, research, education, and outreach activities.

3. Project coordinators should encourage progress and impact reports for components such as greenhouse gas (GHG), soil erosion, runoff, flooding, soil health, nutrient leaching and biodiversity effects be shared as often as practical through field days, presentations, and other participatory stakeholder events.

4. All data should be given rigorous quality assurance and quality control (QA/QC) review before conducting statistical analyses, creating visualization tools, simulation models, or user-friendly decision-support tools.

5. Information delivery should be done using multiple formats such as Case Studies, Technical and Non-technical Publications, and User-friendly websites to enhance impact and effectiveness of multi-stakeholder projects such as this one.

6. Project coordinators should be aware that every stakeholder in complex projects will have a different perspective regarding the most important outcomes. For example, cellulosic feedstock industries producing bioenergy or bio-products will want sustainable inputs with no negative effects on food, feed, or fiber production; producers will want to know that net return on investment (ROI) can be increased; environmental and wildlife groups will want their resources protected, and community leaders will want steady, sustainable economic growth and rural development.

7. Working together to recognize and over-come market, policy, and any type of financial barrier is essential to provide maximum benefit of appropriate Landscape Design visions within and beyond local communities.

8. For maximum impact on complex economic and environmental challenges, such as bioenergy development, soil health, water quality, or rural economic development, partnerships that bridge community, county, state, and regional perspectives will result in local, site-specific, and more cost-effective solutions than independent non-coordinated projects.

9. Diversifying agricultural landscapes and enhancing soil health can provide multiple ecosystem services by decreasing tillage frequency and intensity, wind and water erosion, and loss of soil organic carbon (SOC).

10. Future public-private partnerships addressing sustainability of cellulosic bioenergy and bio-product feedstock production should consider adding stakeholders representing animal production industries. Even though this project included a broad list of project participants additional perspectives and insights should be sought and encouraged to participate. Such an action would significantly advance the economic, environmental, and social impact and sustainability of research investments such as the Landscape Design Project.

Landscape Design Case Studies

No. 1. Subfield Analysis and Management Using Profit Zone Manager™

David J. Muth
dmuthjr@gmail.com

One of the most important products developed, commercialized, and used in this DOE project to improve bioenergy and bio-product feedstock supplies and the potential economic viability of rural America is the Profit Zone Manager™. A conceptual version of the tool was developed in 2013 and given the acronym LEAF (Landscape Environmental Assessment Framework) while I was affiliated with the Bioenergy Research Program at the Idaho National Laboratory (INL). Advancements in LEAF have been continued by INL staff and are described in another Case Study.

Upon leaving INL, I co-founded my first agricultural technology startup known as AgSolver. Profit Zone Manager™ was one of the first products we developed, tested, and marketed to farmers and their consultants with the goal of gaining producer acceptance for practices that will increase cellulosic feedstock supplies and support profitable and sustainable farm operations. Accomplishing the goal, however, was predicated on identifying farming and land management practices that are more profitable than current corn and soybean production. This was especially true if new or additional equipment, more time, or other resources are going to be needed to implement landscape design practices.

A key enabling technology for AgSolver was the emergence of low-cost cloud computing resources (i.e., Amazon Web Services). This provided an incredible platform to affordably scale computations and data processing to the massive levels required for large scale landscape analysis. The algorithms and data processing techniques developed through DOE research could now be commercialized and integrate additional data resources for on-farm and in-field decision making. Many of these data resources are publicly available data including geo-referenced soil survey data from USDA, production costs aggregation provided by land grant universities, market value data, crop identification analyses, and multi-spectral remote sensing. These data resources were integrated with tested algorithms and processes techniques through massively scalable computing resources to evaluate profitability and sustainability at a sub-acre scale in major agricultural production regions across the country. This allowed AgSolver to create high resolution maps predicting return on investment (ROI) for individual fields, entire farms, or any other desired area (e.g., counties or entire states). The accompanying electronic landscape design handbook provides selected examples of how the tool works and allows for limited user input. The critical technical conclusion developed through this process is that from 5 to 20% of U.S. farmland production units (i.e., individual fields or field segments) consistently are non-profitable. Furthermore, many of these same acres are often the primary source of unintended environmental concerns including soil erosion, soil carbon loss, and nutrient loss.

A particular useful, informative, and actionable Case Study for this landscape design approach is known as the Webster Farm and located in North Central Iowa. Figure 1 provides satellite images for the Webster Farm from 2005, 2008, and 2011. All three years provide a clear visual demonstration of vegetative productivity issues through a corridor on the SW corner of the farm. The 2011 image shows clear differentiation between good productivity on the majority of the farm and low vegetative cover in that corridor. Figure 2 represents the soil survey mapping for the Webster Farm. The low productivity corridor in Figure 1 is associated with high sand fraction soils in Figure 2. Soils in that ridge across the SW corridor of the farm create an ongoing challenge for successful row crop production. They are also prone to erosion, nitrate leaching, and suffer from limited water holding capacity.

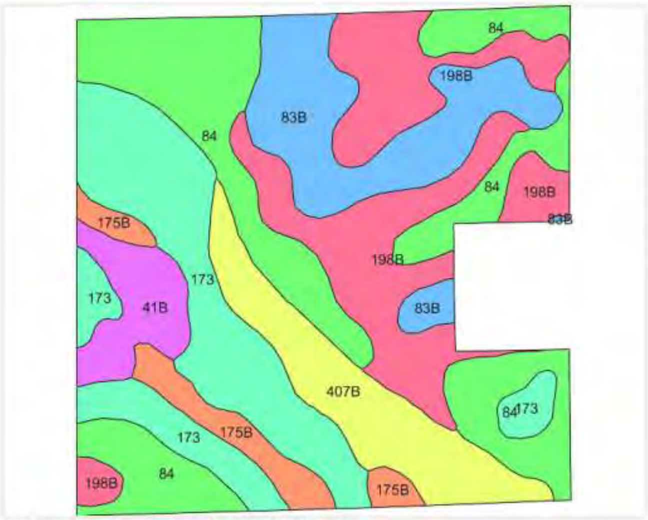
2005 Image

2008 Image

2011 Image

Figure 1. Webster farm satellite images from 2005, 2008, and 2011.

Soils Map



Map Details

State:	IA
County:	Cerro Gordo
QQQ:	SENWSE
Location:	18-94N-19W
Township:	Dougherty township
Acres:	145.1

Soil data is acquired from the USDA-NRCS SSURGO FY2015 product

Code	Soil Description	Acres	% of Field	Non-Irr Class	CSR	CSR2	NCCPI
84	Clyde silty clay loam, 0 to 3 percent slopes	37.4	25.8		88	90	0.86
198B	Floyd loam, 1 to 4 percent slopes	29.9	20.6		89	89	0.86
173	Hoopeston fine sandy loam, 1 to 3 percent slopes	29.8	20.5		55	72	0.67
83B	Kenyon loam, 2 to 5 percent slopes	19.0	13.1		90	91	0.84
407B	Schley loam, 1 to 4 percent slopes	15.1	10.4		81	73	0.85
41B	Sparta loamy fine sand, 2 to 5 percent slopes	7.0	4.8		36	38	0.43
175B	Dickinson fine sandy loam, 2 to 5 percent slopes	7.0	4.8		51	51	0.55
				Weighted Average	**76.7**	**80.1**	**0.78**

Figure 2. Webster Farm soil survey map.

Profit Zone Manager was used to evaluate this farm at a 10m resolution to determine profitability of the unique production areas across the farm. The ‘sand ridge’ area of the farm showed multi-year losses of over $500/acre due to consistently poor productivity (Figure 3). Most of the remaining areas showed consistent ability to generate an ROI for the farmer. This analysis was performed using GPS yield maps collected from the harvesting equipment and generalized costs of production over the analysis years. The next step was to determine what actions could be taken to better utilize the individual areas within this farm to maximize profit and environmental outcomes. The realization that no immediate actions were available to improve the productivity of the sand ridge area quickly pushed the evaluation toward landscape design principles. The critical question became what is the highest, best use of the low productivity zone to simultaneously improve profitability and environmental outcomes. Implementation of perennial vegetation with significant below ground biomass was the clear solution for the environmental outcomes. The next challenge was determining what perennial vegetation could provide a positive economic outcome.

Three primary options for perennial vegetative production were explored: (1) perennial forage crops, (2) biofuels crops, and (3) enrollment in other conservation programs. This region of the country does not have significant forage crop market, so that choice would be very challenging from a farm business perspective. Perennial biofuels crops, particularly switchgrass, could provide a profitable outcome for the farming operation, but at present there was no viable market for biofuel perennials, making that an unwise farming decision. Enrollment in a conservation program that would provide consistent annual payments for the seeding of perennial crop, thus became the clear decision for this farm.

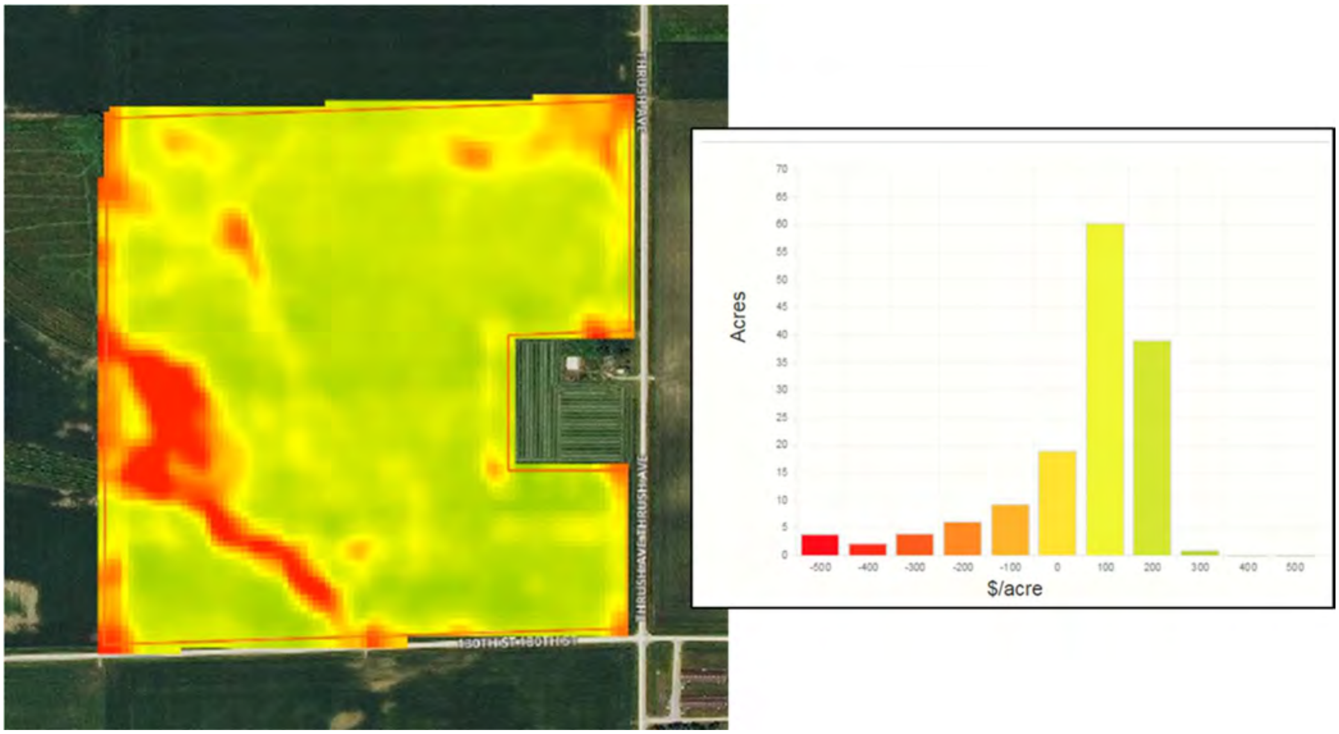
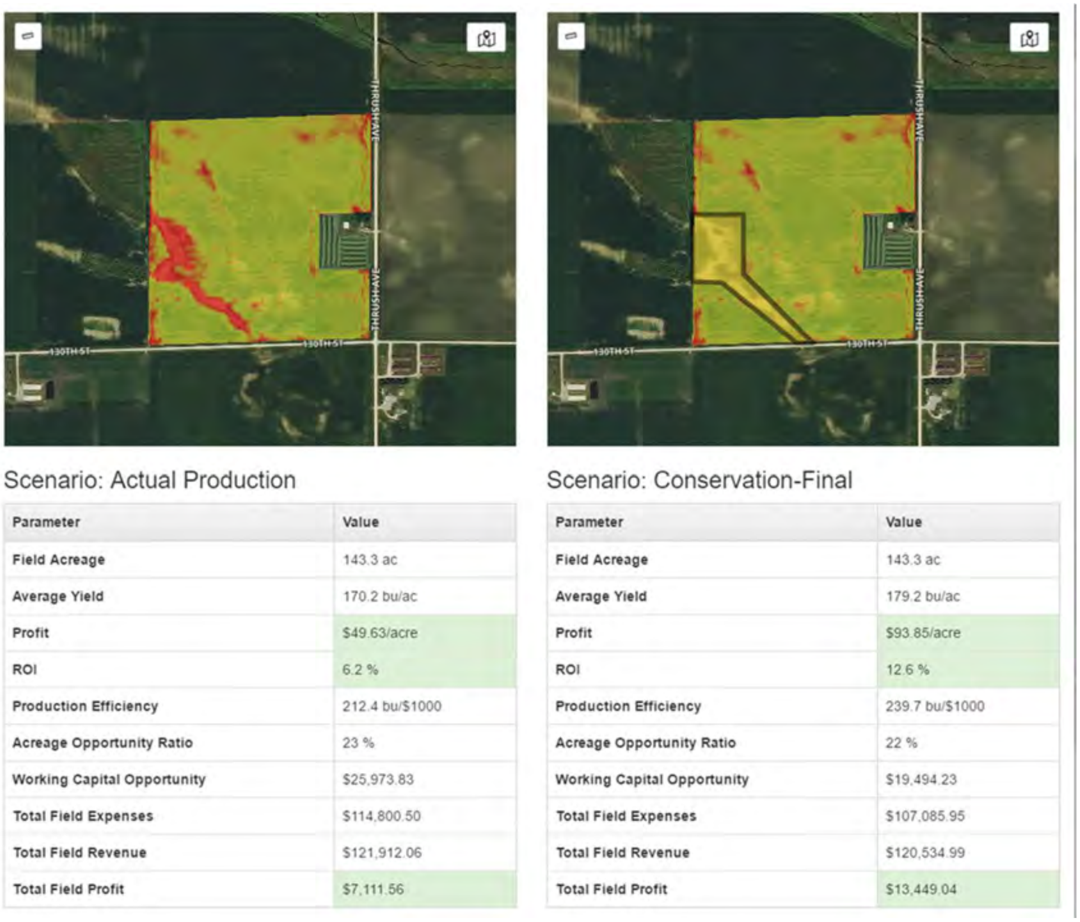


Figure 3. Aggregate profitability over 5 management years.

The sandy ridge corridor (~15 acres) was enrolled into the USDA Conservation Reserve Program (CRP) Pollinator Habitat Practice (Figure 4, right side). The shape of the enrolled zone was calibrated with sharp corners to help the farmer maintain efficient field operations. A Profit Zone Manager analysis of the multi-year impact of implementing this CRP program is presented in the Tables below Figure 4 with (right) and without (left) implementation. Per acre profit increases $44.22 and the ROI more than doubles. While total revenue decreases slightly with this management system, overall profitability increases $6,337.48 for the Webster Farm.

Profitability is a critical decision factor for the farm operator in addressing this management change, but landscape design principles can often provide significant environmental performance benefits and improve profitability. Figure 5 provides the Profit Zone Manager analysis for key environmental performance metrics associated with the management change. Soil loss was calculated by combining (1) the USDA NRCS models RUSLE2 for water erosion and WEPS for wind erosion, and (2) the DAYCENT biogeochemistry model for modeling changes in SOC, NO_3-N, and CO_2 respiration. This integrated modeling framework was deployed on a discretized field grid through Profit Zone Manager at a 10m spatial resolution. Each grid cell is attributed the multi-year yield and management practices to execute the models. Compared to conventional management, the changes reduced soil erosion by nearly 1/3, increased SOC sequestration nearly five-fold, and decreased 5 both NO_3-N and CO_2 losses.



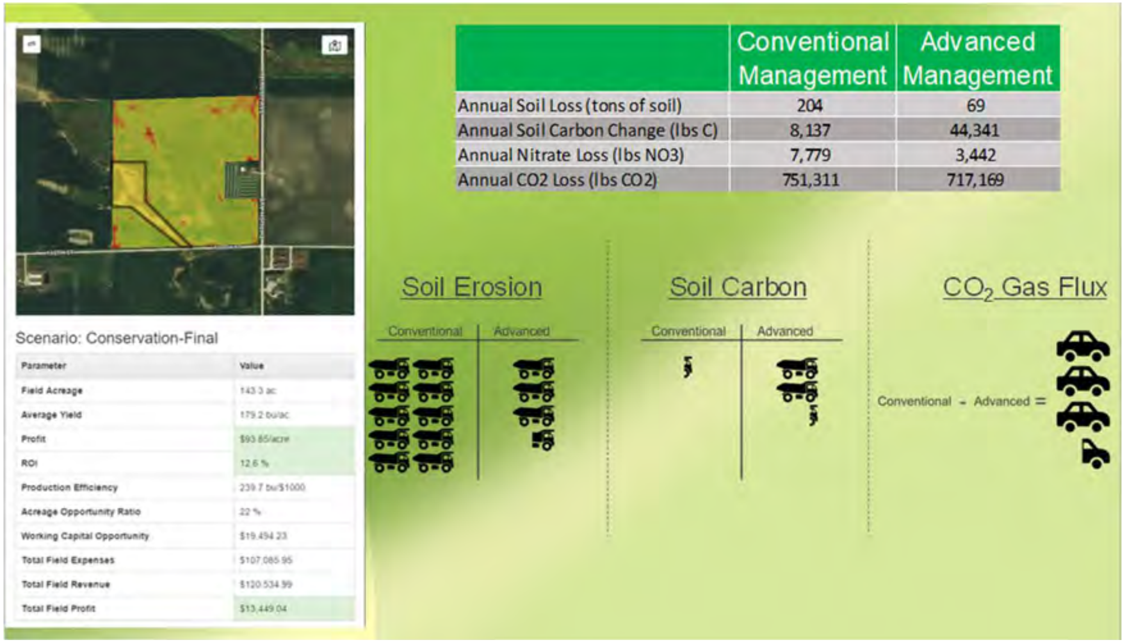
Scenario: Actual Production

Parameter	Value
Field Acreage	143.3 ac
Average Yield	170.2 bu/ac
Profit	$49.63/acre
ROI	6.2 %
Production Efficiency	212.4 bu/$1000
Acreage Opportunity Ratio	23 %
Working Capital Opportunity	$25,973.83
Total Field Expenses	$114,800.50
Total Field Revenue	$121,912.06
Total Field Profit	$7,111.56

Scenario: Conservation-Final

Parameter	Value
Field Acreage	143.3 ac
Average Yield	179.2 bu/ac
Profit	$93.85/acre
ROI	12.6 %
Production Efficiency	239.7 bu/$1000
Acreage Opportunity Ratio	22 %
Working Capital Opportunity	$19,494.23
Total Field Expenses	$107,085.95
Total Field Revenue	$120,534.99
Total Field Profit	$13,449.04

Figure 4. Profit Zone Manager analysis before and after conservation program implementation.



Scenario: Conservation-Final

Parameter	Value
Field Acreage	143.3 ac
Average Yield	179.2 bu/ac
Profit	$93.85/acre
ROI	12.6 %
Production Efficiency	239.7 bu/$1000
Acreage Opportunity Ratio	22 %
Working Capital Opportunity	$19,494.23
Total Field Expenses	$107,085.95
Total Field Revenue	$120,534.99
Total Field Profit	$13,449.04

	Conventional Management	Advanced Management
Annual Soil Loss (tons of soil)	204	69
Annual Soil Carbon Change (lbs C)	8,137	44,341
Annual Nitrate Loss (lbs NO3)	7,779	3,442
Annual CO2 Loss (lbs CO2)	751,311	717,169

Figure 5. Profit Zone Manager environmental impact analysis of CRP implementation.

Ultimately AgSolver and its Profit Zone Manager™ product were sold to EFC Precision Agronomy, a company designed to improve operational efficiencies, generate more revenue per machine/person and provide a higher level of service to its customers. Profit Zone Manager™ was incorporated into FieldAlytics™ which enables the user to manage growers, farms, fields, and boundary profiles online, live track assets, process equipment as-applied layers, planter layers, Veris™ data, yield maps, aerial Imagery and other data layers. It also enables users to manage work orders for fertilizer and pesticide applications, soil sampling, or other common field operational services.

In summary, this Case Study outlines one of the many outstanding impacts of this public-private partnership which became a reality primarily because of the DOE investment in Landscape Design for enhanced cellulosic feedstock supply chains. Those resources were used to build a highly productive team of university, USDA, DOE, and private-sector collaborators whose collective accomplishments will continue to be highlighted throughout the remainder of this report.

No. 2. Field Landscape Decision Support Tool

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Background

Idaho National Laboratory (INL) analysts, in partnership with Landscape Project team members, have developed a decision support tool that suggests where to place perennial grasses within a field. The research and tool development have created new knowledge across scientific disciplines. First, it provided a detailed understanding regarding the diversity of priorities that agricultural producers consider in their decision-making, and the importance (i.e., weight) they assign to them. The decision support tool has facilitated this by combining operations research techniques with social science interviews. Furthermore, this project has illustrated how important stakeholder priorities can be incorporated into agricultural spatial decision-making tools. Overall, the decision support tool used a novel algorithm that ensured the final field layout was operable with current agricultural machinery.

Field operation efficiency was not explicitly considered in identifying stakeholder values with this tool. Although many anticipate a landscape designed based on sustainability preferences will have less operational efficiency than a traditional row crop designed field, this may not be true since the suggested designs can be implemented and are operable with current machinery. The unknown factor is if an alternative landscape design would significantly increase time or labor cost. Those factors obviously impact field operation efficiency, but their relative importance is ultimately determined by stakeholder priorities. For example, if the stakeholder considers water quality, wildlife impacts, soil health, or another long-term sustainability indicator to be more important than short-term profit, the farmer's preferences may significantly influence how a field is planted, thus creating a different farmable area shape, relative to a traditional (rectangles or squares) approach. The alternative field layout (shape) could thus impact operational efficiency.

Allocation of agricultural field segments into perennial grasses or other alternative crops based on stakeholder priorities had not been previously addressed because spatial analysis tools and agricultural equipment that could effectively utilize spatial information have only recently been developed. Some of those tools help farmers decide, based on potential crop yield, how much fertilizer, seed, herbicide, or other crop inputs to apply and where to apply them based on site-specific field segment data. Others are being developed to suggest where conservation crops could have the most impact on soil quality and profitability. The challenge with currently available applications is that they do not account for the diversity of producer priorities or impose specific factors that serve as the basis for landscape decisions. The tool discussed in this Case Study evolved from this Landscape Design project. It uses spatial analysis tools that became available in recent years and input from actual agricultural producers and stakeholders, an advancement that had not been done before.

The Decision Support Tool

Field Landscape Decision Support (FieLDS) is a decision support tool that assists agricultural producers and farm managers with selecting field segments that can be converted from corn and soybean commodity crops to bioenergy crops such as perennial grasses to meet producer's priorities. Conversion recommendations are based on site-specific landscape properties. Using the tool, producers select priorities (i.e., sustainability indicators) that are most relevant to their decision-making and provide spatial [Geographic Information System (GIS)] input for implementing those priorities. Based on each individual's input, FieLDS generates a field layout and spatially marks where to place each type of plant. By allowing users to set weights among their priorities, the tool empowers them to generate field designs specific for their needs rather than those reflecting the developer, biorefinery, or government priorities, thus increasing transparency of the decision process.

The tool was developed as part of the Sustainable Landscape Design project funded by the U.S. Department of Energy to support the establishment of perennial grasses that can be converted to biofuels and biomaterials. The principles and results of this development can be used for planning landscapes with any type of crop or alternate land use.

Who is this tool for?

This tool is designed for agricultural producers and land managers who desire to plant alternative crops such as perennial grasses but are not sure where in the landscape they would fit best. Perennial grasses can be planted for sale to bioenergy markets, as animal bedding, for erosion control, or simply to improve water and soil quality and increase biodiversity. FieLDS is intended to assist producers with diverse priorities – increasing profitability, maintaining soil quality, preventing erosion, ensuring high water quality, and providing employment to enhance rural development. Each priority may be relevant to the producer, but to a different extent. The FieLDS tool allows users with different backgrounds and priorities to tailor complex field designs to meet their specific needs.

The decision support tool was designed based on interviews with agricultural producers. Those interviews generated a list of priorities (sustainability indicators) based on the frequency of discussion. Furthermore, each producer assigned a weight to each priority. Developers can add priorities and spatial inputs if the current list of sustainability indicators does not reflect all factors that they consider relevant for decision-making.

One of the main features of FieLDS is that it not only uses high-resolution spatial input to develop a field layout based on priorities, but also it uses a "smoothing" heuristic to ensure the resulting field designs are easily operable with current agricultural machinery. The "smoothing" process was implemented to avoid a fractured landscape created by only doing pixel-by-pixel comparisons between crop types. Such heuristic techniques were developed specifically for the tool and are time-efficient and easy to implement so that an operable field plan can be generated without requiring resource-intensive optimization calculations.

Inputs

To use FieLDS, a producer specifies the landscape area where the field is located, selects priorities from a list of 15 sustainability indicators (Table 1) and assigns relative weights (i.e., importance) of each indicator (Step 1). Based on the priorities selected, the user enters spatial inputs corresponding to those priorities (Step 2). This is illustrated using an example of spatial input data to predict perennial grass yield. Finally, if desired, users can adjust pre-set utility functions among the priorities as outlined below (Step 3). These three steps are explained in more detail below:

1. *Producer priorities*. The tool is populated with 15 sustainability indicators that producers can choose among and assign weights, but if they are inadequate, new priorities can be added.

2. *Farm information*. Relative to each priority affecting the farmer's decision, farm-specific inputs would include spatial soil and water quality data, profitability goals, and any other relevant factor. Such datasets are available for the State of Iowa as part of the Sustainable Landscape Design Project. Upon request, those data layers can be provided to external users, although if the user is outside of Iowa, they will need to have their own spatial input data. Farm information can be input as either raster or vector files, which are converted to raster files. This results in spatial inputs such as those shown in the raster image below.

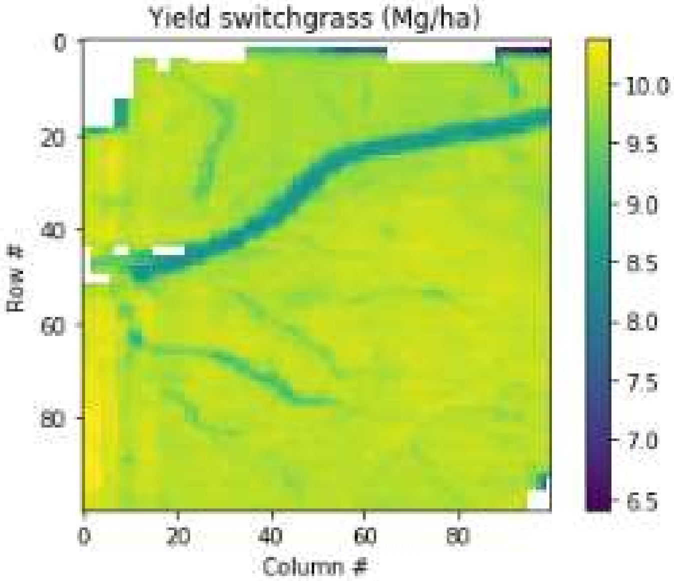

Table 1. Fifteen potential sustainability indicators available within FieLDS.
(Adapted from Table 4-1 in Vazhnik, 2020)

No.	Indicator
1.	Independence (ratio of profit from subsidies to profit from competitive markets)
2.	Financial stability (profit/risk due to income variability cause by market and weather)
3.	Profitability (calculated based on yield and crop budgets)
4.	Annual crop yield
5.	Diversification (potential number of markets)
6.	Water quality (NO_3-N in runoff)
7.	Soil quality (soil organic carbon)

8. Wildlife and pristine nature probability estimate (based on literature for each crop)
9. CO_2 emissions (Calculated on a CO_2 equivalent basis)
10. Erosion potential (RUSLE calculated erosion rate)
11. Food production and animal feed (% area under food production)
12. Rural development (number of total on-farm jobs)
13. Positive image (scores reflect consumer-approval of literature-based practices)
14. Farming lifestyle (score assumption for the ability to maintain a family operation)
15. Inheritability and young farmer opportunities (land value as a function of soil management and long-term farm profitability)

3. The decision support tool has a set of utility functions for each sustainability indicator that are pre-set. If desired, users can modify the utility function or add more priorities/spatial inputs depending on the availability of information.

Documentation

On GitHub you will find Python code that can be used to process spatial inputs and generate a landscape layout. It is available at https://github.com/idaholab/FieLDS . The document is intended for a technical audience because it does not contain a Graphical User Interface (GUI) but rather presents the actual code for spatial analysis. The code might be changed in the future as more optimization features are added to the tool.

Technical details

The developed code references several Python libraries. Spatial data were processed using Python 3.6.9 language in Jupyter Notebook (https://jupyter.org/) with Geographic Information Systems (GIS) processing packages for spatial data processing: rasterio 1.0.21, pandas 0.25.3, geopandas 0.4.1, matplotlib 3.1.1., georasters 0.5.15 and numpy 1.17.4.

Outputs

What can you expect from using the tool? FieLDS will generate a field layout with suggested placement of annual and perennial crops. Tangible benefits from using the tool and proposed crop layouts include helping farmers and landowners understand where perennial grasses would best fit within their individual fields. Adopting the recommendations would potentially improve farm profitability, diversify agricultural production, improve water and soil quality, and provide better habitat for wildlife. If the grass is harvested, it can serve as feedstock for bioenergy or biomaterials.

Reference

Vazhnik, Veronika. "Farm Landscape Design Decision Support to Increase Economic, Environmental and Social Benefits Using Stakeholder Engagement, Sustainability Assessment and Spatial Analysis". Dissertation in BioRenewable Systems for The Pennsylvania State University. May 2020. 230 pages.

No. 3. Biodiversity Impacts of Landscape Design

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BACKGROUND

Midwest US agricultural landscapes have been homogenized by the increase in corn, soybean, and other commodity crops. As a result, bird, wildlife, and pollinator populations have decreased significantly (Benton, Vickery, & Wilson, 2003). Some species are adversely affected though loss of reproduction habitat (Best, Bergin, & Freemark, 2001), while others are unable to find appropriate cover in homogenized agricultural landscapes. Increasing landscape heterogeneity provides more varied habitats for wildlife, greater opportunity for food acquisition, and overall increased biodiversity (Benton, Vickery, & Wilson, 2003).

Despite the expansion of traditional row crops, there are areas of the landscape that are poorly suited for annual crops and that consistently produce lost revenue for farmers (Bonner et al., 2014). Incorporating perennial and warm-season grasses such as switchgrass into current cropping systems could provide multiple benefits, including production of cellulosic biomass feedstocks and the restoration of wildlife habitat (Werling et al., 2014). Areas of low return on investment could be converted to switchgrass production for bioenergy. For example, Brandes et al. (2018) demonstrated that the conversion of low producing corn/soybean cropland to switchgrass in Iowa would net upwards of $13.6 billion USD (Brandes et al., 2018).

Benefits of perennial grasses on avian diversity have been documented in terms of providing post-breeding and migratory stopover habitat (Robertson et al., 2011a). Generally, grasses are considered to provide better habitat for birds than traditional row-crops such as corn (Robertson, et al., 2011b). Insect pollinators may also be more successful in heterogeneous landscapes where forbs and soy and other insect-pollinated plants provide possible habitat. Bennett et al. (2014) showed that converting annual crops on marginal soil to perennial grasslands could increase bee abundance from 0 to 600% and increase bee diversity between 0 and 53%.

METHODOLOGY

Our goal was to determine how different species would respond to planting switchgrass in areas of low return on investment (ROI). To examine the relationship between predictors and species' probability of occurrence, we built a species distribution modeling (SDM) tool called BioEST (Bioenergy-biodiversity Estimation) (Jager, Wang, Kreig, Sutton, & Busch, 2017; Efroymson et al., 2017). An SDM relates species occurrence with environmental and habitat conditions where the species was found (Citores et al., 2020). In this study, we used BioEST to generate occurrence models for 28 species. We examined how species responded to presence of corn, soybean, grassland, distance to water and distance to forest. We considered grassland a proxy for switchgrass and other perennial grasses grown as biomass feedstocks.

BioEST Development

Our research team developed an enhanced species distribution model (SDM), BioEST (Jager, Wang, Kreig, Sutton, & Busch, 2017), to determine the impact of growing biomass crops on biodiversity. BioEST is novel because it accounts for the effect biomass crops are expected to have on wildlife occurrence either through incorporating response ratios that reflect how species densities vary among land management types or through direct use of relevant predictors (as here). Inputs to the model are environmental predictors and species data points. As outputs, BioEST calculates the probability of species presence or 'occupancy' in a location. Given this probability, we are able to create maps of predicted species occurrence. The overview diagram in Figure 1 shows data inputs, model information, and outputs.

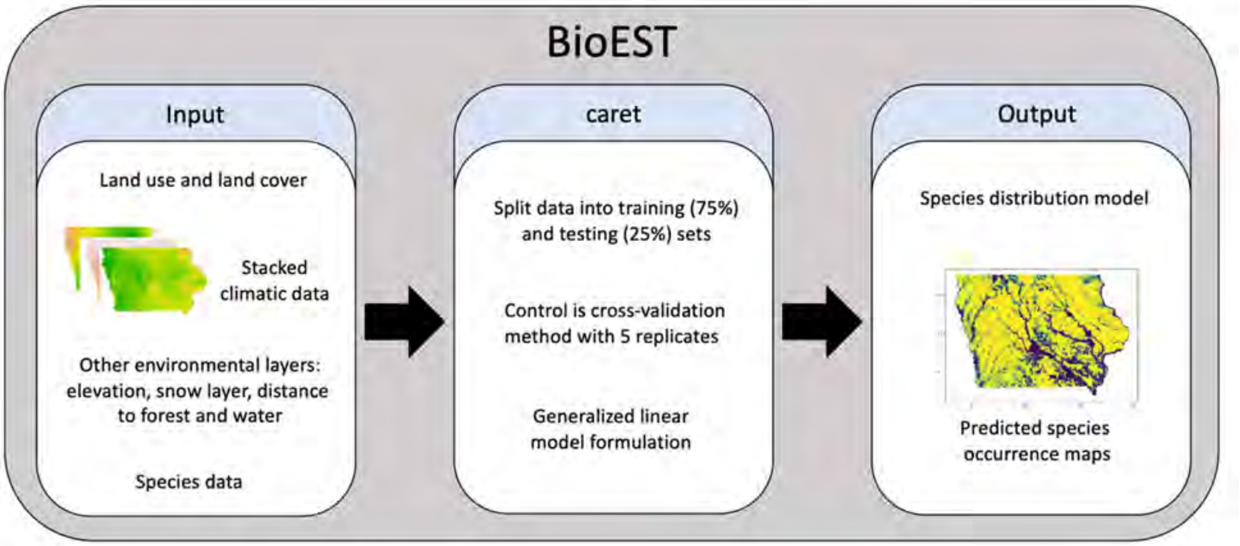

Figure 1 - BioEST model diagram including inputs, model building that occurs in caret, and outputs.

SDMs require data on the presences and absences of a species across a landscape to estimate the probability of occurrence in a location (Guisan et al., 2013). We obtained species presence data from the Global Biodiversity Information Facility website (https://www.gbif.org/). The search area for recorded species occurrence was restricted to the state of Iowa. We excluded fossil records, records without geographic coordinates, and records dated prior to 1990.

Following the BioEST diagram (Figure 1), we gathered predictor data as 1 km x 1 km rasters and combined them. Descriptions of predictor data are detailed below. Using this raster stack of predictors, we obtained predictor values for locations of each recorded species presence as well as each inferred pseudo-absence. In order to generate a model that determines probability of species occurrence, we need both presence and absence data with which to train the model. Because we do not have absence data for species, we create pseudo-absence data points for the model to use instead. Pseudo-absence data were generated by randomly selecting locations that were not presence points within the study area (Barbet-Massin, Jiguet, Albert, & Thuiller, 2012). The same number of pseudo-absences were selected as the number of presence points for a species. From there, we used the Classification and Regression Training (caret) package in R

(Kuhn, 2019) to create our SDM. We split the dataset into training (75%) and testing (25%) datasets. Using the cross-validation method with 5 replicates, we used the generalized linear models (GLM) method to create SDMs for each species. We assessed each SDM by calculating a confusion matrix using the test dataset. From the confusion matrix, we calculated model accuracy and the omission error. An accuracy value of 0.5 denotes a random predictor. Any model with accuracy below 0.7 (Araújo et al., 2019) was discarded from further analysis. Omission error is the percent of presence points that are predicted absent, or the percent of false negatives.

Environmental Predictors

Our analysis spans the state of Iowa, USA, at 1 km^2 resolution. We acquired 19 climatic GIS data layers (1 km^2 resolution) from the WorldClim global climate database (“Worldclim - Global Climate Data,” 2019) and clipped them to the spatial extent of Iowa. Land-use data were obtained from the 2009 National Agriculture Imagery Program (NAIP) (Farm Service Agency & Agriculture, 2009) and resampled via nearest neighbor from 1 m to 1 km resolution. Digital elevation data, originally 30 m and resampled using nearest neighbor to 1 km, were acquired from an USGS National Map (Map, 2020). We also included snowfall accumulation (in meters) over a season (September 30 2016 – September 30 2017). Snowfall data (1-km x 1-km resolution) were gathered from the National Snowfall Analysis which is a part of the National Weather Service under the National Operational Hydrologic Remote Sensing Center (Service, 2019).

A common problem in model building occurs when predictors are highly correlated. This results in unstable coefficient estimates. To reduce collinearity among predictors, correlations between indicators were calculated, and if they were highly correlated ($r > 0.7$) only one was included in the analysis (Gogol-Prokurat, 2011). All predictors that matched this criterion were investigated, and the predictor that was more important ecologically (e.g., maximum temperature would be more important than average temperature, because some species may perish at high temperatures) was kept. Finally, we removed the predictors that had near-zero variance. Table 1 lists all of the predictors used in the BioEST model.

Many predictors are needed to forecast the spatial distribution of wildlife, but not all of them could be considered important predictors of wildlife responses to perennial biomass crops. We included distance to forest (m) and distance to water (m) as predictors, as these variables are relevant to riparian buffers, which can also be planted and harvested as biomass crops. Proximity to forest and water are likely to be important for some wildlife taxa (e.g., amphibians, bats). Data layers were created by identifying water and forest features from the resampled NAIP 2009 land-use raster (1-km resolution), creating an empty mask grid, calculating the nearest distance between grid cells and selecting features using the nearest neighbor algorithm in QGIS, the free and open-source cross-platform desktop geographic information system application, v3.10.3.

Table 1 - All 13 predictors included in BioEST, including the name of the predictor, a description of the predictor, and the original data source.

Predictor Name	Description	Temporal Resolution	Source
Bio 2	Mean diurnal temperature range	1970-2000	(“Worldclim - Global Climate Data,” 2019)
Bio 8	Mean temperature of wettest quarter		
Bio 9	Mean temperature of driest quarter		
Bio 15	Precipitation seasonality		
Bio 16	Precipitation of wettest quarter		
Bio 17	Precipitation of driest quarter		
DEM	Digital elevation model, elevation (m)	2020 (1 year)	(Map, 2020)
Corn	Presence of corn	2009 (1 year)	(Farm Service Agency & Agriculture, 2009)
Soybean	Presence of soybean		
Grassland	Presence of grassland (past and future)		
Forest dist	Distance to forest (m)	2009 (1 year)	(Farm Service Agency & Agriculture, 2009)
Water dist	Distance to water (m)		
Snow	Season accumulation of snow fall (m)	September 30 2016 – September 30 2017	(Service, 2019)

Future landscapes—planting grasses in areas of low ROI

In addition to creating SDMs based on current conditions, BioEST can also be used as an evaluative tool for potential future landscapes. BioEST can produce maps of biodiversity; here we measure biodiversity as total species richness, or the total number of species present in an area.

For this project, areas of low ROI were identified across Iowa using procedures summarized in Case Study No. 7. We then created a future landscape in which these areas of low ROI were converted to grassland. We then used BioEST to evaluate the probability of species occurrence given this future landscape. We also calculated the total species richness of each landscape by summing richness across all species and area in our study. Finally, we mapped current and future biodiversity levels (Figure 3) in order to evaluate the biodiversity implications of a future landscape where areas of low ROI have been converted to grassland.

MODEL EVALUATION

We developed models for 28 species initially chosen from two main sources: Iowa Department of Natural Resources’ list of Endangered and Threatened Species (Department of Natural Resources, 2019) and the Iowa Gap Analysis Program (GAP) analysis (Kane, Klaas, Anderson, & McNeely, 2004). Most, but not all species in this analysis are considered species of concern. Of all the potential species, 28 were kept because their model accuracy was greater than 0.7 (Table 2).

Table 2 - Scientific name, species name, taxa, number of presence points, model accuracy, and the omission error for each of the 28 species included in this analysis.

Scientific name	Species	Taxa	Number of presences	Accuracy	Omission error
Aix sponsa	Wood duck	Bird	6707	0.78	0.2
Archilochus colubris	Ruby-throated hummingbird	Bird	4400	0.79	0.2
Asio otus	Long-eared owl	Bird	160	0.76	0.08
Aythya collaris	Ring-necked duck	Bird	3501	0.78	0.22
Aythya marila	Greater scaup	Bird	466	0.88	0.09
Bombus auricomus	Black and gold bumblebee	Insect	61	0.87	0.13
Buteo lineatus	Red-shouldered hawk	Bird	970	0.81	0.17
Chlidonias niger	Black tern	Bird	886	0.77	0.22
Circus cyaneus	Hen harrier	Bird	63	0.77	0.2
Colinus virginianus	Northern bobwhite	Bird	1028	0.77	0.19
Corvus brachyrhynchos	American crow	Bird	17600	0.76	0.24
Fulica americana	American coot	Bird	5629	0.79	0.2
Haliaeetus leucocephalus	Bald eagle	Bird	14101	0.77	0.23
Icterus galbula	Baltimore oriole	Bird	7084	0.76	0.23
Icterus spurius	Orchard oriole	Bird	1924	0.72	0.3
Lophodytes cucullatus	Hooded merganser	Bird	2976	0.81	0.17
Meleagris gallopavo	Wild turkey	Bird	5451	0.74	0.23
Molothrus ater	Brown-headed cowbird	Bird	9309	0.73	0.27
Odocoileus virginianus	White-tailed deer	Mammal	103	0.76	0.32
Piranga olivacea	Scarlet tanager	Bird	1732	0.8	0.23
Piranga rubra	Summer tanager	Bird	542	0.83	0.13
Quiscalus mexicanus	Great-tailed grackle	Bird	480	0.72	0.25
Quiscalus quiscula	Common grackle	Bird	13337	0.71	0.32
Rallus limicola	Virginia rail	Bird	315	0.74	0.29
Sciurus niger	Fox squirrel	Mammal	86	0.76	0.24
Scolopax minor	American woodcock	Bird	519	0.79	0.19
Sterna forsteri	Forster’s tern	Bird	1020	0.86	0.11
Zenaida macroura	Mourning dove	Bird	15192	0.72	0.29

RESULTS

Species Response to Environmental Predictors

To determine how different species would respond to increased grassland on the landscape we used the odds ratio, which measures each species' response to a specified predictor. The odds ratio is calculated by taking the exponential of the coefficient for a particular predictor (odds ratio = $e^{\beta j}$, where β is the logistic coefficient for predictor *j*). For every increase of 1 unit in predictor values, the probability that a species is present increases by the odds ratio. For example, the estimated odds that a Fox squirrel (*Scurius niger*) is present is 1.27 greater for each increase in the presence of grassland. By the same token, for each increase in the presence of grassland, the estimated odds of a Hooded merganser (*Lophodytes cucullatus)* being present decreases by 0.99. Responses for all 28 species to corn, soybean, grassland landcover and distance to forest are displayed in Figure 2.

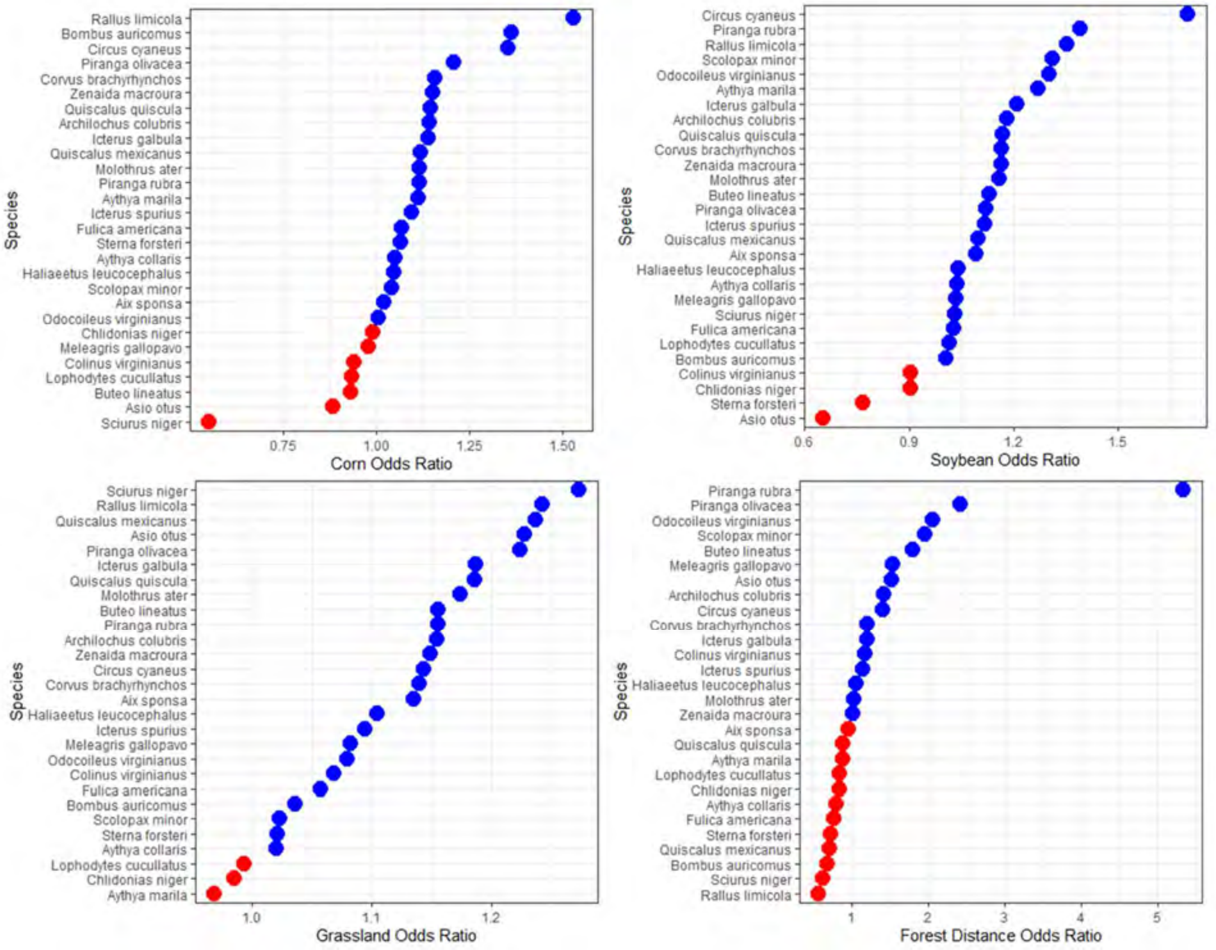

Figure 2 - Species response to (beginning in top left) corn, soybean, grassland, and forest distance. Response is calculated as the odds ratio and displayed in blue if the species responds positively to the predictor, and red if the species responds negatively.

We expected to see more negative responses to corn and soybean since these cash crops can disturb habitat for wildlife. However, when considering the high protein food sources that corn and soybeans provide to wildlife (Bogenschutz et al., 1995), it makes sense that 75% of species and 85.7% of species responded positively to corn and soybeans, respectively. The food source that biomass feedstocks can potentially provide to wildlife are not taken into account for this study. Because the presence of grassland was used as a proxy for perennial grasses grown for biomass, the fact that we saw 89.2% of the species in our study respond positively to grassland supports our hypothesis that wildlife will take advantage of the habitat requirements that biomass feedstocks could provide. This assumes that the negative effect of management (e.g., harvest etc.) of grasses for biomass feedstock is small.

When considering distance to forest, we see an interesting split in species response: 42.9% of species responded negatively to distance from forest (i.e., they are less likely to be observed further away from the forest), whereas 57.1% of species responded positively. This means that over half of the species in this study are more likely to occur on a landscape if they are not near forest. As such, forest land that is near water could be converted to riparian buffers of bioenergy crops and biodiversity would not be significantly impacted. For the 42.9% of species that respond positively to forested habitat, introducing short-rotation woody crops may be a solution to producing biomass feedstocks without adversely affecting some wildlife.

Species Responses to Planting Grasses in Areas with Low ROI

Maps of current and future species richness are displayed in Figure 3.

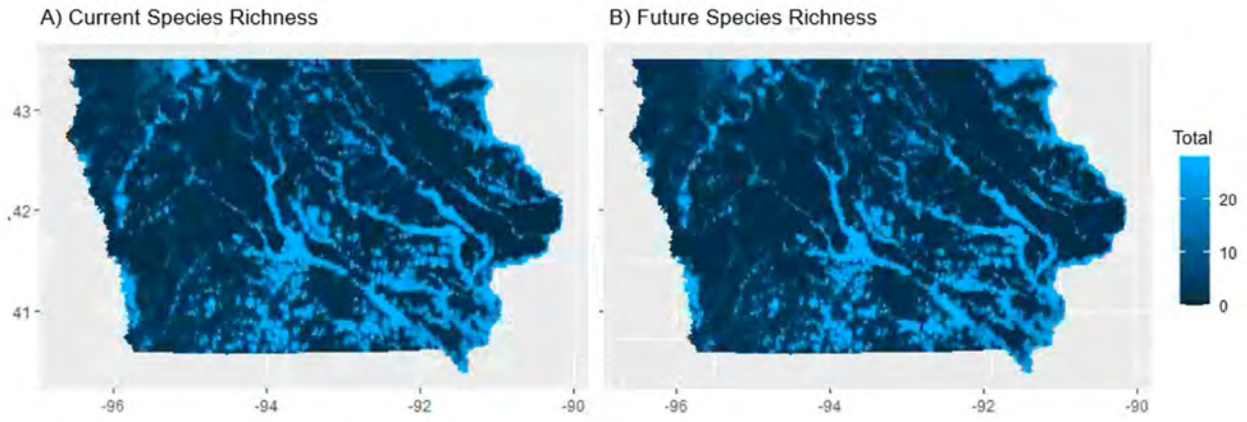

Figure 3 – Maps of (A) current species richness (total richness: 1480842), and (B) projected species richness (total richness: 1593078) under a future landscape where areas of low ROI were converted to grassland.

The percent change in richness for each species between the two landscapes (Table 3) shows the projected impact on individual species, rather than the total richness. The Great-tailed grackle (*Quiscalus mexicanus*) experienced the largest increase (19.2%), while the Greater scaup (*Aythya marila*) experienced the largest decrease (-3.3%). Of all 28 species, only three—the Greater scaup, Black tern, and Hooded merganser—experienced a decline in occurrence under a future landscape where areas of low ROI have been converted to grassland.

Table 3 - Scientific name, species name, past richness, future richness, and percent change of species occurrence between past and future landscapes.

Scientific name	**Species**	**Past Richness**	**Future Richness**	**Percent Change**
Aix sponsa	Wood duck	48464	53897	11.2%
Archilochus colubris	Ruby-throated hummingbird	44894	49070	9.3%
Asio otus	Long-eared owl	59006	69204	17.3%
Aythya collaris	Ring-necked duck	52375	53093	1.4%
Aythya marila	Greater scaup	37472	36246	-3.3%
Bombus auricomus	Black and gold bumblebee	64072	64567	0.77%
Buteo lineatus	Red-shouldered hawk	43422	47109	8.5%
Chlidonias niger	Black tern	56006	55634	-0.66%
Circus cyaneus	Hen harrier	72648	74511	2.5%
Colinus virginianus	Northern bobwhite	66656	69662	4.5%
Corvus brachyrhynchos	American crow	51771	56773	9.7%
Fulica americana	American coot	49317	51501	4.4%
Haliaeetus leucocephalus	Bald eagle	47257	51140	8.2%
Icterus galbula	Baltimore oriole	49506	55844	12.8%
Icterus spurius	Orchard oriole	56816	60173	5.9%
Lophodytes cucullatus	Hooded merganser	44059	43972	-0.2%
Meleagris gallopavo	Wild turkey	59146	63011	6.5%
Molothrus ater	Brown-headed cowbird	54715	62321	13.9%
Odocoileus virginianus	White-tailed deer	57329	59196	3.3%
Piranga olivacea	Scarlet tanager	39701	44876	13%
Piranga rubra	Summer tanager	44873	47224	5.2%
Quiscalus mexicanus	Great-tailed grackle	59211	70597	19.2%
Quiscalus quiscula	Common grackle	53072	62389	17.6%
Rallus limicola	Virginia rail	61274	69100	12.8%
Sciurus niger	Fox squirrel	60995	68156	11.7%
Scolopax minor	American woodcock	59015	59125	0.19%
Sterna forsteri	Forster's tern	34965	35764	2.3%
Zenaida macroura	Mourning dove	52806	58923	11.6%

Visual comparisons of current and projected species richness maps are difficult, so we created a difference map to highlight areas where changes in species richness occurred (Figure 4). Additionally, because we are measuring biodiversity as species richness, we were able to calculate the total richness of a landscape. Based on those calculations, projected biodiversity was increased by 7.8%, simply by converting areas of low ROI to grassland.

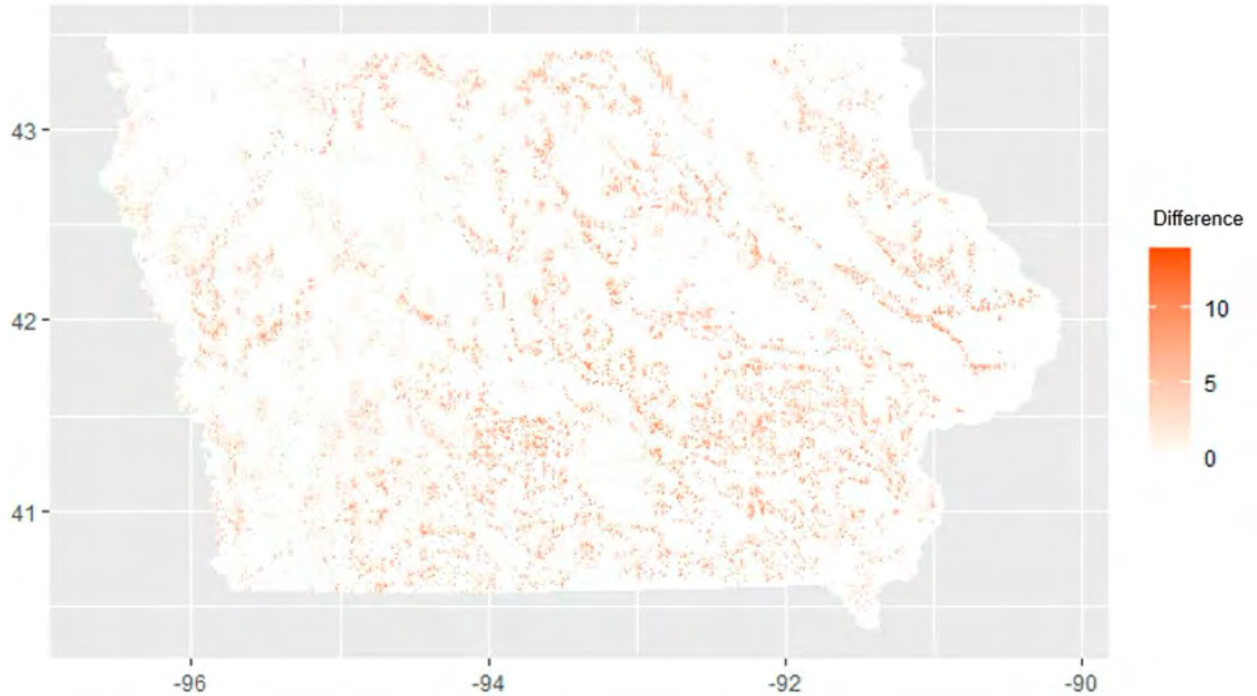

Figure 4 – Difference map between current and future landscapes.

CONCLUSIONS

- Increasing the amount of perennial biomass feedstocks produced in Iowa may increase biodiversity for species of concern (see Figure 3)
- Most species (89.2%) had a positive response to grassland presence, which we suggest can be considered a proxy for bioenergy switchgrass plantings. Note that the majority of species here were birds.
- Future analyses will need to consider food sources for wildlife, since positive response of species to presence of corn (75%) and soybean (85.7%) indicate some use of this kind of habitat
- BioEST has shown that it can effectively evaluate the biodiversity of future landscapes. Given this, we could also run a future climate scenario to see how species may be impacted by a changed climate.
- Conversion of some forested land to bioenergy riparian buffers or introduction of short-rotation woody crops are two landscape design options for increasing biomass feedstock production without adversely affecting biodiversity
- Biodiversity (measured as species richness) would increase 7.8% if all low ROI acres identified in Iowa were converted to grassland
- Areas of low ROI tended to occur in riparian areas. Given this and the approximately 8% increase in biodiversity that would result if these areas were to be converted to grassland, there is a strong argument for introducing bioenergy riparian buffers into the landscape.
- BioEST successfully projected biodiversity implications of alternative landscape designs and can be useful for illustrating those effects through biodiversity maps.

REFERENCES

Araújo, M. B., Anderson, R. P., Márcia Barbosa, A., Beale, C. M., Dormann, C. F., Early, R., … Rahbek, C. (2019). Standards for distribution models in biodiversity assessments. *Science Advances*, *5*(1), eaat4858. https://doi.org/10.1126/sciadv.aat4858

Barbet-Massin, M., Jiguet, F., Albert, C. H., & Thuiller, W. (2012). Selecting pseudo-absences for species distribution models: How, where and how many? *Methods in Ecology and Evolution*, *3*(2), 327–338. https://doi.org/10.1111/j.2041-210X.2011.00172.x

Beckmann, M., Gerstner, K., Akin-Fajiye, M., Ceaușu, | Silvia, Kambach, S., Kinlock, N. L., … Seppelt, R. (2019). Conventional land-use intensification reduces species richness and increases production: A global meta-analysis. *Global Change Biology*, *25*, 1941–1956. https://doi.org/10.1111/gcb.14606

Bennett, A. B., Meehan, T. D., Gratton, C., & Isaacs, R. (2014). Modeling Pollinator Community Response to Contrasting Bioenergy Scenarios. *PLoS ONE*, *9*(11), e110676. https://doi.org/10.1371/journal.pone.0110676

Benton, T. G., Vickery, J. A., & Wilson, J. D. (2003). Farmland biodiversity: is habitat heterogeneity the key? *Trends in Ecology & Evolution*, *18*(4), 182–188. https://doi.org/10.1016/S0169-5347(03)00011-9

Best, L. B., Bergin, T. M., & Freemark, K. E. (2001). Influence of Landscape Composition on Bird Use of Rowcrop Fields. *The Journal of Wildlife Management*, *65*(3), 442. https://doi.org/10.2307/3803096

Bogenschutz, T. R., Hubbard, D. E., & Leif, A. P. (1995). Corn and sorghum as a Winter Food Source for Ring-Necked Pheasants. *The Journal of Wildlife Management*, *59*(4), 776–784. Retrieved from https://www-jstor-org.proxy.lib.utk.edu/stable/pdf/3801956.pdf?refreqid=excelsior%3A84621a4a1c1de1044bab198f911c094b

Bonner, I., Cafferty, K., Muth, D., Tomer, M., James, D., Porter, S., & Karlen, D. (2014). Opportunities for Energy Crop Production Based on Subfield Scale Distribution of Profitability. *Energies*, *7*(10), 6509–6526. https://doi.org/10.3390/en7106509

Brandes, E., Plastina, A., & Heaton, E. A. (2018). Where can switchgrass production be more profitable than corn and soybean? An integrated subfield assessment in Iowa, USA. *GCB Bioenergy*, *10*(7), 473–488. https://doi.org/10.1111/gcbb.12516

Citores, L., Ibaibarriaga, L., Lee, D. J., Brewer, M. J., Santos, M., & Chust, G. (2020). Modelling species presence–absence in the ecological niche theory framework using shape-constrained generalized additive models. *Ecological Modelling*, *418*(January), 108926. https://doi.org/10.1016/j.ecolmodel.2019.108926

Department of Natural Resources, I. (2019). Iowa's Threatened and Endangered Species. Retrieved from https://www.iowadnr.gov/conservation/iowas-wildlife/threatened-and-endangered

Efroymson, R. A., Langholtz, M. H., Johnson, K., Stokes, B., Brandt, C. C., Davis, M. R., … Dale, V. H. (2017). *2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 2: Environmental Sustainability Effects of Select Scenarios from Volume 1*. Oak Ridge, TN (United States). https://doi.org/10.2172/1340460

Farm Service Agency, & Agriculture, U. S. D. of. (2009). NAIP Imagery. Retrieved from https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/

Gogol-Prokurat, M. (2011). Predicting habitat suitability for rare plants at local spatial scales using a species distribution model. *Ecological Applications*, *21*(1), 33–47. https://doi.org/10.1890/09-1190.1

Guisan, A., Tingley, R., Baumgartner, J. B., Naujokaitis-Lewis, I., Sutcliffe, P. R., Tulloch, A. I. T., … Buckley, Y. M. (2013). Predicting species distributions for conservation decisions. *Ecology Letters*, *16*(12), 1424–1435. https://doi.org/10.1111/ele.12189

Jager, H. I., Wang, G., Kreig, J. A. F., Sutton, N. J., & Busch, I. K. (2017). *Simulated Response of Avian Biodiversity to Biomass Production*.

Kane, K. L., Klaas, E. E., Anderson, K. L., & McNeely, R. L. (2004). Iowa Gap Analysis Project. https://doi.org/10.13140/2.1.1095.9689

Kuhn, M. (2019). caret. Retrieved from http://topepo.github.io/caret/index.html

Map, N. (2020). Elevation Dataset. Retrieved from https://www.usgs.gov/core-science-systems/ngp/3dep/about-3dep-products-services?qt-science_support_page_related_con=0#qt-science_support_page_related_conNational Agriculture Statistics Survey. (2019). *Iowa Ag News – Chemical Use*.

Rivas Casado, M., Mead, A., Burgess, P. J., Howard, D. C., & Butler, S. J. (2014). Predicting the impacts of bioenergy production on farmland birds. *Science of the Total Environment, The*, *476–477*, 7–19. https://doi.org/10.1016/j.scitotenv.2013.12.080

Robertson, B. A., Doran, P. J., Loomis, E. R., Robertson, J. R., & Schemske, D. W. (2011a). Avian use of perennial biomass feedstocks as post-breeding and migratory stopover habitat. *PLoS ONE*, *6*(3). https://doi.org/10.1371/journal.pone.0016941

Robertson, B. A., Doran, P. J., Loomis, L. R., Robertson, J. R., & Schemske, D. W. (2011b). Perennial biomass feedstocks enhance avian diversity. *GCB Bioenergy*, *3*(3), 235–246. https://doi.org/10.1111/j.1757-1707.2010.01080.x

Service, N. W. (2019). National Snowfall Analysis. Retrieved from https://www.nohrsc.noaa.gov/snowfall/index.html?season=2016-2017&date=2020050712&version=0

Werling, B. P., Dickson, T. L., Isaacs, R., Gaines, H., Gratton, C., Gross, K. L., … Landis, D. A. (2014). Perennial grasslands enhance biodiversity and multiple ecosystem services in bioenergy landscapes. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(4), 1652–1657. https://doi.org/10.1073/pnas.1309492111

Worldclim - Global Climate Data. (2019). Retrieved from www.worldclim.com

No. 4. Iowa Agriculture Bio-Fibers (IABF) Collaboration Benefits

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This case study is written from the perspective of a private sector business that was operational for eight years before this Landscape Design was initiated, but none-the-less received substantial benefit as a project collaborator. The mission of IABF is to practice sustainable agriculture and lean manufacturing for better soil and water quality as well as reduced Green House Gas (GHG) emissions. Our trademarked FiberFactor® Feeds provide farmers and feeders a superior way to raise livestock, enhance animal health and generate additional revenues. IABF believes that healthier animal feed leads to food safety for Americans.

Over the past 12 years IABF has developed and marketed 40+ new products in the areas of livestock feed, biofuel, biochemical, and bioproducts. IABF now averages 15,000 tons of finished products and has revenues of over $2 million annually. IABF always took pride in harvesting and maintaining high-quality stover feedstock for its many products but did not necessarily have a complete understanding of how to assess and share the important balance between soil health indicators, feedstock production, and sustainable crop yields with our producers. Collaboration with USDA-Agricultural Research Service (ARS), US-Department of Energy (DOE), universities and other private-sector partners on this project provided insights that enabled IABF to create its trademarked Biomass Processing System™ (BPS).

The IABF Biomass Processing System™ has successfully addressed several industry challenges while creating high value FiberFactor® Feed products. IABF discovered that some people did not believe farmers could successfully remove biomass from their fields without damaging the soil and hurting future yields. Participating in this landscape design project made IABF more aware of USDA research guidelines that showed that soils were healthier, retained more moisture and actually produced greater grain yields in future years, if the right amount of biomass was removed. Although corn stover and other crop residues are often regarded as low value by-products of grain harvest, IABF discovered that when corn stover was augmented with other co-products and processed into FiberFactor® Feeds, the pellets provided a high value complete feed for animals.

Other companies tried to produce biomass products without optimizing each step in the biomass value chain process: Harvesting, Handling, Storing, Grinding, Mixing, Pelleting, Drying and Packaging. IABF optimized the biomass value chain by inventing unique processing techniques for each step, making the product more and more valuable as raw materials progressed through the multi-step process.

Through the collaborations with landscape project participants, livestock nutritionists and Veterinarians, IABF learned that grazing animals require a good balance of microbes in their gut to maximize feed value from what they eat. FiberFactor® Feeds creates an environment in the gut that enables microbes to flourish, thereby feeding the animals in a healthy manner. Put another way, producers feed their animals the biomass, but microbes in the gut generate the nutrients that feed the animals. In fact, IABF believes that FiberFactor® functions as a super probiotic for livestock.

IABF also learned that the Biomass Processing System™ releases C5 and C6 sugars in FiberFactor® Feeds. This is important because it means IABF has created a feed that is much more digestible and that the animal (through their gut microbes) can obtain maximum nutrient benefit from what they ingest. Furthermore, these sugars increase palatability for the animals. Palatability is critical for growth. If a livestock animal does not like the taste of a feed, they will eat less. If they eat less, they cannot grow and perform as well. IABF dealers and customers report that FiberFactor® Feeds boost animal performance and appearance. IABF thinks that the FiberFactor® pellet is a product that is healthier for livestock than any other pelleted feed product on the market.

In addition to the above-mentioned collaborations, which resulted in production of better IABF agricultural products and practices, our staff helped the DOE and USDA project managers plan for and facilitate more effective team meetings and workshops. Alan Chute, IABF's co-owner has: a BS in mathematics and PhD in Instructional Technology; is a Lean Six Sigma Instructor; Master Black Belt; and ThinkTank™ facilitator. ThinkTank™ is a group decision support system that enables meeting participants to brainstorm ideas, prioritize alternatives and vote on solutions in an accelerated timeframe. Alan collaborated with the Landscape Design research team and helped facilitate the project kickoff meeting in Ames, Iowa.

ThinkTank™ was subsequently used for leveraged cellulosic feedstock harvest, storage, and transportation studies, after being purchased by the Idaho National Laboratory (Richard Hess). Alan Chute then helped facilitate a ThinkTank™ workshop with project co-PI (Douglas Karlen) who coordinated a national workshop in Sacramento, California on behalf of the American Society of Agronomy (ASA). The ASA workshop was entitled "Crop Residues for Advanced Biofuels: Effects on Soil Carbon." The workshop brought together agronomists, soil scientists, modeling experts, industry representatives, producers, and regulators to discuss the latest knowledge and understanding regarding crop residue management and LCA research. The ultimate goal achieved by the workshop was to capitalize on the collective scientific knowledge of members of ASA, CSSA, and SSSA to provide regulators with the best science-based information available regarding the complex challenges of managing crop residues, sustaining or enhancing soil organic matter (SOM), reducing GHG emissions, and producing cellulosic-based advanced biofuels and other bio-products.

Project collaboration activities using the Think Tank™ software helped disseminate early results and lessons learned from the Landscape Project. Numerous interactions and collaborations with the Landscape Design project team were very beneficial for the IABF Company and were professionally rewarding for IABF personnel.

No. 5. Demonstrating Landscape Design Through Perennial Grass Conservation Programs

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One Landscape Design approach for increasing bioenergy feedstock supplies, enhancing soil health, and protecting water quality is to increase use of perennial grasses within various land management scenarios. This can be done by planting perennial species on highly erodible fields or field segments with low ROI (Return on Investment), incorporating vegetative strips into row crops to reduce slope length, or planting poorly drained or drought prone soils in swales or on ridgetops to perennial grasses or pollinator crops.

Currently, potential U.S. markets for perennial grass feedstock are limited to a few operations, such as the University of Iowa Biomass Fuel Project and the Cooperative Farm to Fuel Project in Virginia. The latter was initiated and is being coordinated by one of our Landscape Design partners, FDC Enterprises Inc. To incorporate perennials in this project, efforts were focused on two specific activities: (1) replanting expiring Conservation Reserve Program (CRP) sites or converting low ROI business as usual (BAU) corn and soybean fields in the same areas of Iowa to perennial mixtures approved for the CP-38 program under current CRP legislation; and (2) quantifying agronomic business plans, feedstock logistics, as well as planting and harvesting strategies for switchgrass and other warm-season species associated with the VA project.

The CP-38 conversion component of this project focused primarily on the logistics of identifying suitable sites that would be representative of the POET-DSM and Nevada Fuelsheds, working with the USDA NRCS and Farm Service Agency (FSA) to develop seed mixtures that would be suitable for cellulosic bioenergy production and meet the conservation needs associated with the overall CRP program, and determining a soil health baseline for those conversion sites. The soil health assessment was initially planned to encompass before and after measurements, but for multiple reasons beyond the control of the project team, the five-year timeframe for this project was sufficient only for (i) establishing baseline values for two landscape positions (low and high slope) and three treatment scenarios and (ii) preparing producer-friendly soil health assessment documentation for land-owners and operators. Those activities were coordinated by the ARS team members and are summarized in Case Study Number 10.

Specific tasks associated with the large-scale VA project included developing collaborative demonstration fields to highlight specific conservation and/or bioenergy feedstock production related practices that can be easily implemented by landowners throughout the nation. This included documenting real-world challenges associated with implementing 1,500 to 2,000 acres of mixed warm season grass energy crops. The team also sought to identify cover crop demonstration sites where logistics associated with that Landscape Design activity could be quantified. Goals, hypotheses, and accomplishments associated with those activities are summarized in Case Study Number 9.

Challenges and accomplishments associated with the large-scale switchgrass project in VA are summarized in a digital on-line Landscape Design Handbook accompanying this report. Video clips highlighting individual activities associated with switchgrass management are shown in Figure 1 and the overall Landscape Design associated with the VA switchgrass component of the study is shown in Figure 2. Other video clips included in the digital handbook highlight multi-stakeholder outreach activities such as field days at various sites. Those were held to educate producers, conservationists, other research and outreach personnel, and policy makers about Landscape Design and demonstrate various conservation and harvest practices.

Switchgrass height and density Mowing the switchgrass Raking the switchgrass

Baling the switchgrass Bale collection logistics Transport logistics

Figure 1. Switchgrass management and logistics quantified by Project Investigators (PIs).

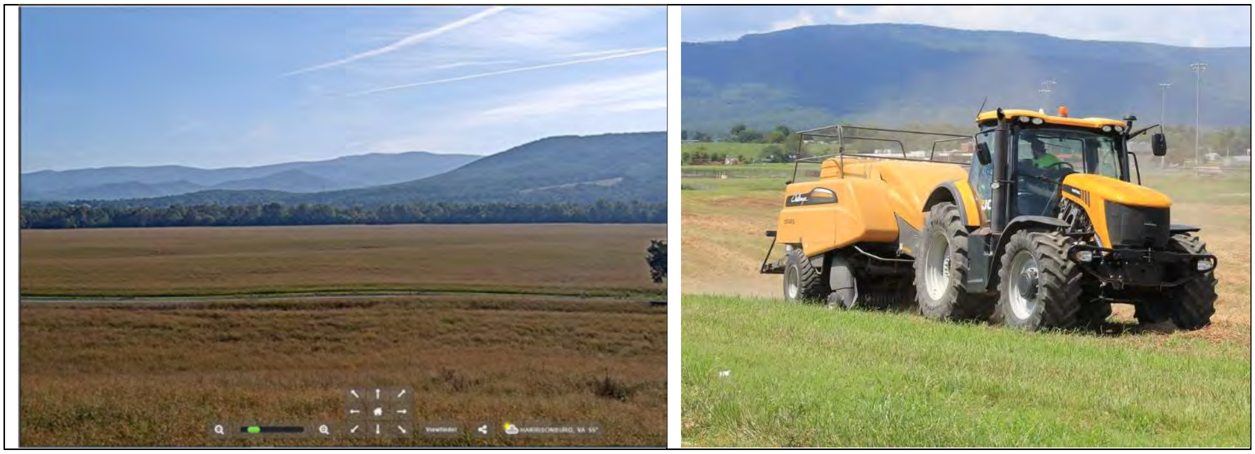

Figure 2. Switchgrass evaluations lead by FDC team members on 580 acres near Elkton, VA.

No. 6. Estimating Wind Erosion Potential of Stover Harvest in the Central Plains

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This Landscape Design project was designed to enhance bioenergy feedstock supplies for the POET-DSM, DuPont, and Abengoa bio-refineries. The latter, serving the Central Great Plains of Kansas, Colorado, and Oklahoma, was unique because two critical ecosystem services provided by crop residue in the Great Plains are water conservation through reduced evaporation, as well as wind erosion prevention. To quantify stover harvest effects on potential wind erosion, soil aggregate size distribution, surface random roughness, and crop biomass, data were collected for six dates from two sites each in eastern and western Kansas (Table 1). The three parameters were measured during Spring and Fall of 2017 through 2019. Similar measurements were anticipated for 2020 and although samples were collected, Covid disruptions slowed laboratory analyses and interpretation. The wind erosion soil parameters were summarized for use with the Wind Erosion Prediction System (WEPS) model to estimate effects of biomass harvest on wind erosion potential and associated changes in soil particle-size distribution and organic matter.

Table 1. Site information.

Site	Soil	Management	Irrigation	Annual precipitation mm*	Sampling Dates following Spring & Fall
Colby, KS	Ulysses silt loam 1-3% slopes	No till, continuous corn since 2009	sprinkler ~305 mm yr^{-1}	534	2017: 6/26 & 10/30 2018: 4/20 & 12/18 2019: 6/12 & 12/9 2020: Covid Delay
Ottawa, KS	Woodson silt loam 0-1% slopes	No till, continuous corn since 2009	none	1105	2017: 6/27 & 11/21 2018: 5/17 & 12/20 2019: 6/13 & 11/19 2020: Covid Delay

* For the period of study (2016-2019).

Maintaining vegetative cover on the soil surface is the most effective and practical method for controlling wind erosion (Siddoway et al., 1965; Woodruff et al., 1977). In addition, soil random roughness (RR) and dry aggregate size distribution (ASD) are temporal soil erodibility parameters affecting wind erosion. Changes in these erodibility parameters over time are known to be moderated by crop residue cover (Skidmore et al., 1986). With increasing levels of biomass removal, the potential exists for increased soil erodibility because of increased exposure to wind forces and reduced aggregate size and random roughness of the exposed soil surface. In addition, wind erosion is a selective process removing the finer and lighter portions of the soil, thus potentially reducing soil clay and organic matter contents along with associated soil health. The objective of this study component was to quantify effects of crop biomass removal on potential soil loss by wind erosion and associated changes in particle-size distribution and soil organic matter contents.

The Landscape Design project leveraged a biomass removal experiment that was established on no-till corn fields at each location in 2009. Similar studies (see He et al., 2018) have been conducted on plots with only a few years of biomass removal. This study was unique because it had much longer-term residue removal treatments (i.e., 9+ years). At both sites, the planting date each year was approximately May 6th with harvest around October 30th. The plant population was 12,343 plants per hectare (1.2343 plants m^{-2}). Following corn grain harvest, stalks were mowed at a height of approximately 50 mm and residue was removed from 6 m x 6 m plots at levels of 0, 25, 50, 75, and 100% of above-ground biomass. Each removal treatment was replicated three times in a randomized block design. Spring and Fall are typically the most wind erosion prone seasons in the study area (Presley and Tatarko, 2009). Since the wind erodibility parameters measured are temporal and vary by season, ASD and RR were sampled in Spring and Fall of 2017, 2018, and 2019 at both sites. Data for those dates will be merged with prior years before preparing a final peer-reviewed journal article.

ASD affects wind force on the soil surface as well as the fraction of erodible-size particles. ASD samples were taken using a flat bottom shovel from the upper 50 mm of soil in each plot. A rotary sieve (Lyles et al., 1970) was used to separate dry aggregates into size classes and associated mass fractions in seven size categories: <0.42-, 0.42 to 0.84-, 0.84 to 2.0-, 2 to 6.35-, 6.35 to 14.05-, 14.05 to 44.45-, and >44.45-mm in diameter. The wind erodible fraction (EF) and geometric mean diameter (GMD) were calculated using sieving mass fractions. The EF is the percentage of aggregates <0.84 mm in diameter, which are considered the size typically removed by wind (Chepil & Woodruff, 1963). Within the EF, aggregates between 0.84 and 0.1 mm are moved by saltation and creep transport, generally being deposited locally within or near field boundaries. The < 0.1 mm fraction consists of suspension sized particles that can be removed from the field and transported long distances. The <0.42 mm sample was therefore sieved to also obtain the suspension fraction (SF). Both EF and SF will be analyzed for particle size distribution (PSD) and soil organic matter (SOM) content to estimate the potential for changes in soil particle size and removal of SOM due to wind erosion. GMD is a WEPS input parameter used to determine wind erosion potential under various residue levels.

RR affects wind force and provides trapping and storage of eroding particles. RR is a measure of micro-elevation differences at the soil surface resulting from aggregates or other non-oriented soil disturbances as the result of tillage (i.e., ridges). For each sampling, a microrelief pin meter as described by Wagner & Yu (1991) was used to measure RR along ridge tops of each plot. RR was calculated as the standard deviation of pin heights after correction for slope (Allmaras et al., 1966; van Donk & Skidmore, 2003). Three RR measurements were made and averaged for each plot.

EF, GMD, and RR data will be used as WEPS model inputs to simulate wind erosion for soils under the corn management and residue removal levels at each site. WEPS is a computer-based model developed by the USDA-ARS to provide an accurate, universal, and simple tool for simulating soil wind erosion as affected by management and weather for a given soil. It is used by the USDA-Natural Resources Conservation Service (NRCS) and others for conservation planning to reduce wind erosion (Tatarko et al., 2019). We will use the Single-event Wind

Erosion Evaluation Program (SWEEP), the erosion submodel of WEPS, to simulate effects of biomass removal on wind erosion.

Measured EF, GMD, and RR parameters will be input into SWEEP to determine the effect of these parameters on soil loss as affected by biomass removal levels for single-day events. Other soil input parameters (e.g., sand, silt, and clay contents) will be obtained by the SWEEP model interface based on the mapped soil type at each site. Other soil temporal input parameters (e.g., crust extent and aggregate stabilities) will be based on typical values for the soils simulated and held constant for the simulations. SWEEP will be used to predict the wind velocity needed to initiate wind erosion as well as to compare the total soil loss under each crop residue removal level at a wind velocity of 13 m s^{-1} for three hours. The probability of reaching threshold wind velocity (i.e., the wind velocity at which soil erosion initiates) and the percent of days that wind velocities exceeding threshold levels can be expected in the sampling month will be determined by the SWEEP model using historical wind parameters from the model database for each site. SWEEP simulated soil loss will provide estimates of biomass removal levels that are sustainable and will keep soil loss to tolerable levels. The soil loss simulations will also provide a basis to estimate potential changes in particle size and SOM under various biomass removal levels. These results will be beneficial to the DOE since they can be extrapolated to other locations and wind regimes with similar crops and soil types, within the Landscape Design project area.

Results of this study will provide general guidance for regional private sector land managers regarding levels of corn biomass that can be sustainably harvested and still control soil erosion and protect SOM stocks. However, we anticipate site-specific evaluations using SWEEP or WEPS will still be needed to confirm local soil responses to crop residue removal. Results will also provide information regarding potential changes in PSD and SOM in response to biomass removal.

References:

Allmaras R.R., R.E. Burwell, W.E. Larson, and R.F. Holt. 1966. Total porosity and random roughness of the interrow zone as influenced by tillage. USDA Conservation Research Report 7, 22 pp.

He, Y., D.R. Presley, J. Tatarko, H. Blanco-Canqui. 2018. Crop residue harvest impacts wind erodibility and simulated loss in the Central Great Plains. Global Change Biology and Bioenergy. 10:213-226.

Lyles, L., J.D. Dickerson, and L.A. Disrud. 1970. Modified rotary sieve for improved accuracy. Soil Sci. 109(3):207-210.

Presley, D. and J. Tatarko. 2009. Principles of Wind Erosion and its Control. K-State Research and Extension Publication MF-2860.

Siddoway, F.H., W.S. Chepil, and D.V. Armbrust. 1965. Effect of kind, amount, and placement of residue on wind erosion control. Trans. ASAE 8:327-331.

Skidmore, E.L., J.B. Layton, D.V. Armbrust, and M.L. Hooker. 1986. Soil physical properties as influenced by cropping and residue management. Soil Sci. Soc. Am. J. 50(2):405-419.

Tatarko, J., L. Wagner, and F. Fox. 2019. The Wind Erosion Prediction System and its use in conservation planning. In: Bridging among disciplines by synthesizing soil and plant processes. In: O. Wendroth, R. Lascano, L. Ma, Eds. Adv. Agric. Syst. Model. 8:72-101. ASA, CSSA, and SSSA, Madison, WI.

van Donk, S.J. and E.L. Skidmore. 2003. Measurement and simulation of wind erosion, roughness degradation and residue decomposition on an agricultural field. Earth Surface Processes and Landforms 28(11):1243-1258.

Woodruff, N.P., L. Lyles, F.H. Siddoway and D.W. Fryrear. 1977. How to control wind erosion. U.S. Department of Agriculture, Agricultural Research Service, Agriculture Information Bulletin No. 354, 22 pp.

No. 7. Sustainability Evaluation of Landscape Design Alternatives

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Collaboration between the Iowa Landscape Design (Iowa LD) team and two US DOE BETO-funded projects led by Oak Ridge National Laboratory (ORNL)—"Quantifying & Visualizing Progress Toward Sustainability" (4.2.2.40) and "Scientific Methods for Biomass Reference Scenarios" (3.1.4.001)—has advanced capabilities to assess economic and environmental effects of alternative landscape designs at fuel-shed and watershed scales. Here we summarize results from four alternative landscape management scenarios for the Nevada Fuelshed area and the South Fork Watershed located in north central Iowa (**Figure 1**). The results of these assessments document that alternative landscape designs defined by the Iowa LD team have substantial potential for providing multiple benefits across both spatial extents, including diverse feedstocks for fuel, fodder, and food production, increased biodiversity habitat, improvements to soil and water quality, increased soil carbon sequestration for climate change mitigation, and cost savings through reduced fertilizer use.

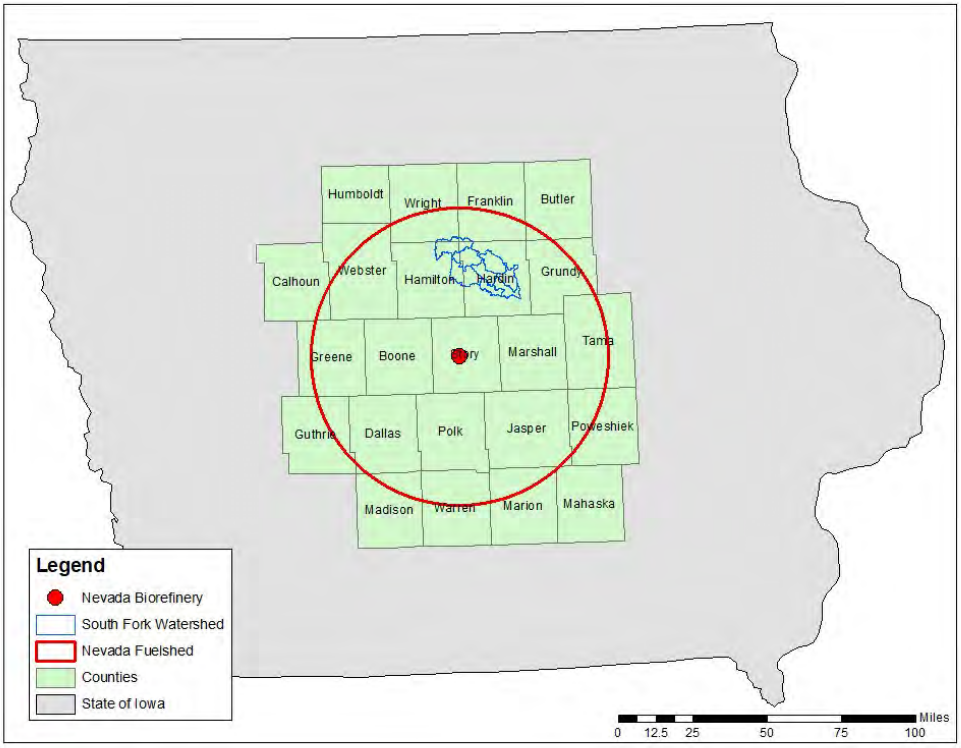


Figure 1. Location of the Nevada Fuelshed and South Fork Watershed landscapes within Iowa

A systematic indicator-based approach for comparing options and assessing progress toward sustainability goals selected in conjunction with stakeholders (Dale et al. 2019) was applied in coordination with collaborators in the Landscape Design Project. As shown in **Figure 2**, this is an iterative approach that involves six steps: (1) define the scope and objectives of the assessment based on the particular context; (2) identify indicators that can be used to monitor trends or alert pending concerns and select them based on practical utility and relevance; (3) establish baseline and target values for each indicator that can be used to compare alternative scenarios; (4) collect data to assess changes in indicator values over time; (5) analyze indicator trends and potential synergies/tradeoffs among them; and (6) develop good practices that can be shared with other bioenergy projects. Success of this process depends on stakeholder engagement, effective communication, transparency, and monitoring. Iterative application of the approach promotes continual improvements in practices, which enable responses to changing conditions while moving toward a more sustainable future. The Iowa Landscape Design project provided the opportunity to apply this sustainability assessment approach to assess alternative management scenarios involving multiple cellulosic feedstocks (i.e., switchgrass and corn stover) as well as conventional crops.

Figure 2. Six steps and cross-cutting insights for assessing progress toward sustainability goals (Dale et al., 2019)

During initial discussion with Iowa stakeholders described in Dale et al. (2018), the Iowa LD team selected a set of environmental and socioeconomic sustainability indicators that could be used to assess progress toward three main goals: (1) Produce sufficient & profitable cellulosic feedstock supply for commercial-scale biofuels production; (2) Reduce nitrate and phosphorus runoff from nonpoint sources to meet Iowa Nutrient Reduction Strategy goals; and (3) Improve pheasant populations for recreational hunting. Over the period of one year, partners in the Iowa LD team contributed ideas and feedback to develop a set of four, clearly defined, alternative land management scenarios to compare using this set of indicators. It was important to start by defining a project baseline (a.k.a., business-as-usual) to represent common practices and conditions for typical Iowa corn and soybean rotations from 2013-2016, the years immediately preceding cellulosic biomass production. Defining potential alternative scenarios of cellulosic bioenergy production was particularly challenging because many Iowa LD team members were conducting research that focused on different specific goals and management practices (e.g., variable corn stover removal rates, manure applications, use of cover crops, soil organic carbon management and measurement) discussed in other chapters of this report.

In January 2020, the Iowa LD team reached consensus regarding four alternative landscape management scenarios to evaluate and compare with regard to potential sustainability outcomes: (1) continuing corn/soybean cropping at historic (i.e., 2013-2016) rates with no new conservation practices or biomass markets (**Base Case Scenario**); (2) corn/soybean cropping at historic rates with some new conservation practices (e.g., reduced till) but no biomass markets (**Improved Management Scenario**); (3) planting bioenergy switchgrass on clusters of unprofitable or low return on investment (ROI) corn and soybean subfields, coupled with ~30% corn stover harvest from suitable fields, harvest of rye cover crop biomass for additional cellulosic feedstock, and adoption of no-till on the most erosive fields (**Integrated Landscape Design A**); and (4) planting bioenergy switchgrass on clusters of unprofitable or low ROI corn and soybean subfields, coupled with ~45% corn stover harvest from suitable fields, harvest of rye cover crop biomass for additional cellulosic feedstock, adoption of no-till on all fields, and perennial Conservation Reserve Program (CRP) plantings on the remaining 14% of low ROI acres (**Integrated Landscape Design B**).

ORNL used ArcGIS software to assemble and integrate the Profit Zone Manager dataset and 7 of the 48 AgSolver crop management simulations for Iowa's corn/soy acres described in Case Study 1 to match the four landscape management scenarios. After preparing subfield-scale geospatial layers for each scenario (**Figure 3**), ORNL then calculated and aggregated environmental and socioeconomic indicator values for each scenario across the Nevada Fuelshed and the South Fork Watershed.

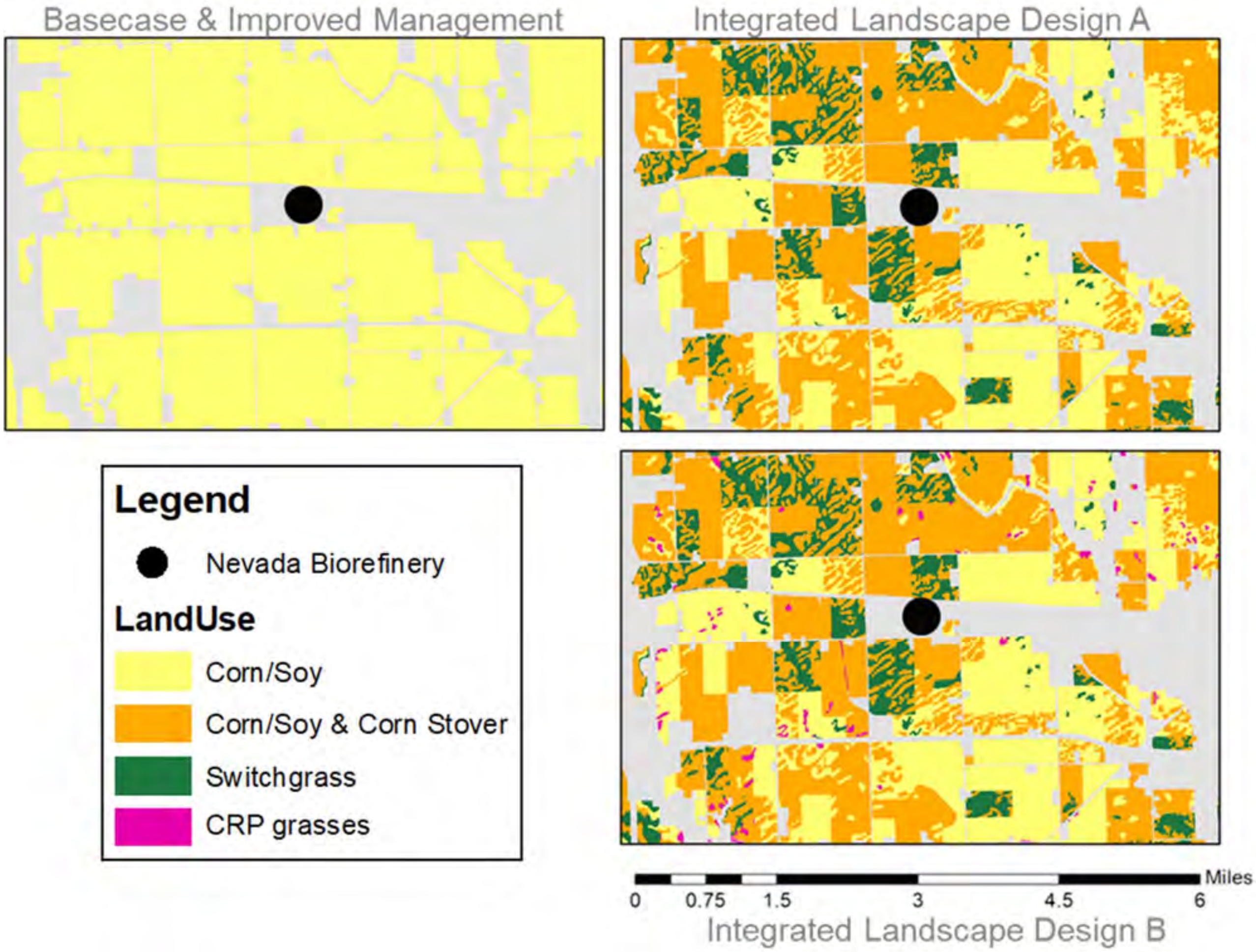
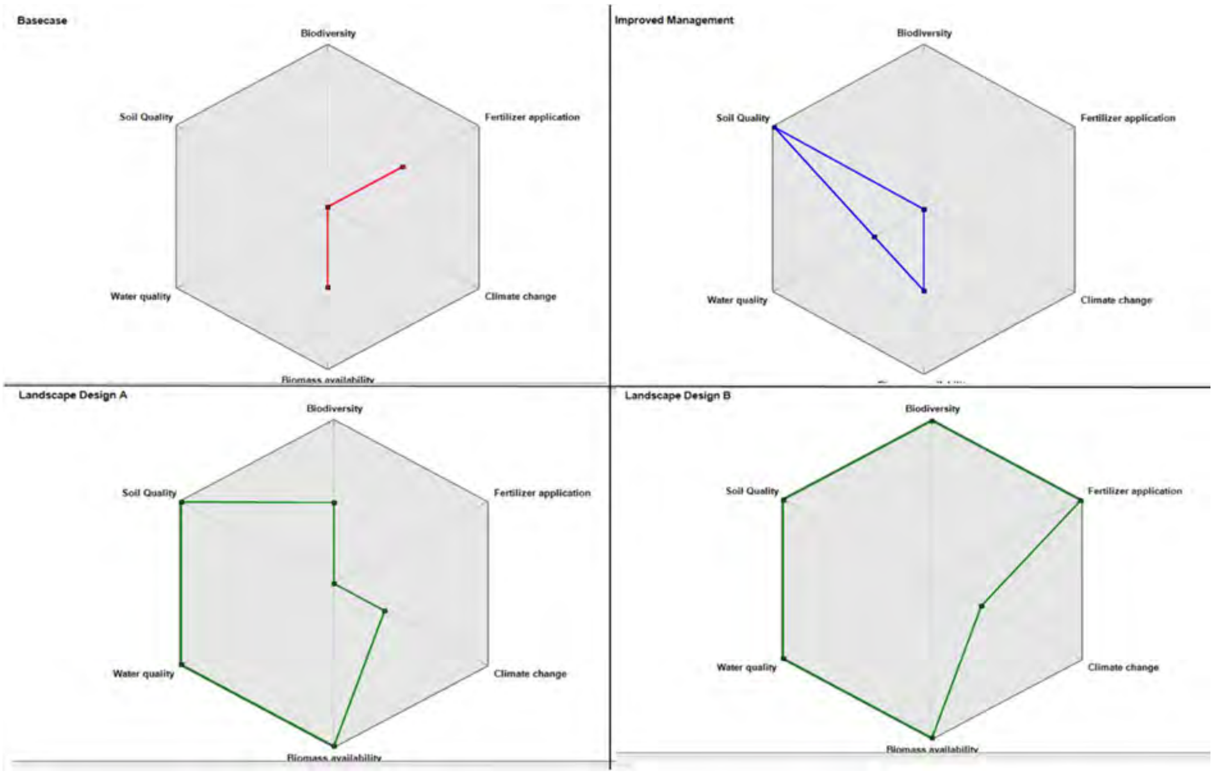


Figure 3. Comparison of agricultural field types within ~3 miles of the Nevada Biorefinery under the four different scenarios. All acres are in corn/soy under the Base Case and Improved Management scenarios (upper left). Under Integrated Landscape Design A (upper right), switchgrass replaces corn/soy on clustered unprofitable subfields, and under Integrated Landscape Design B (lower right) CRP grasses replace corn/soy on some additional scattered unprofitable subfields. As part of the Integrated Landscape Design scenarios, corn stover is removed from some of the corn/soy acres to be used for bioenergy production.

Building from work described in Parish et al. (2016), these quantitative indicator values were used to build qualitative sustainability evaluation models with DEXi 5.04 software. The sustainability models were used to evaluate and visualize potential tradeoffs between indicators assessed for each scenario as well as the overall relative sustainability of the four alternative landscape design scenarios at the fuelshed extent (**Figure 4**) and the watershed extent (**Figure 5**). A summary of the relative sustainability outcomes at the Nevada Fuelshed extent is shown in **Figure 6**.

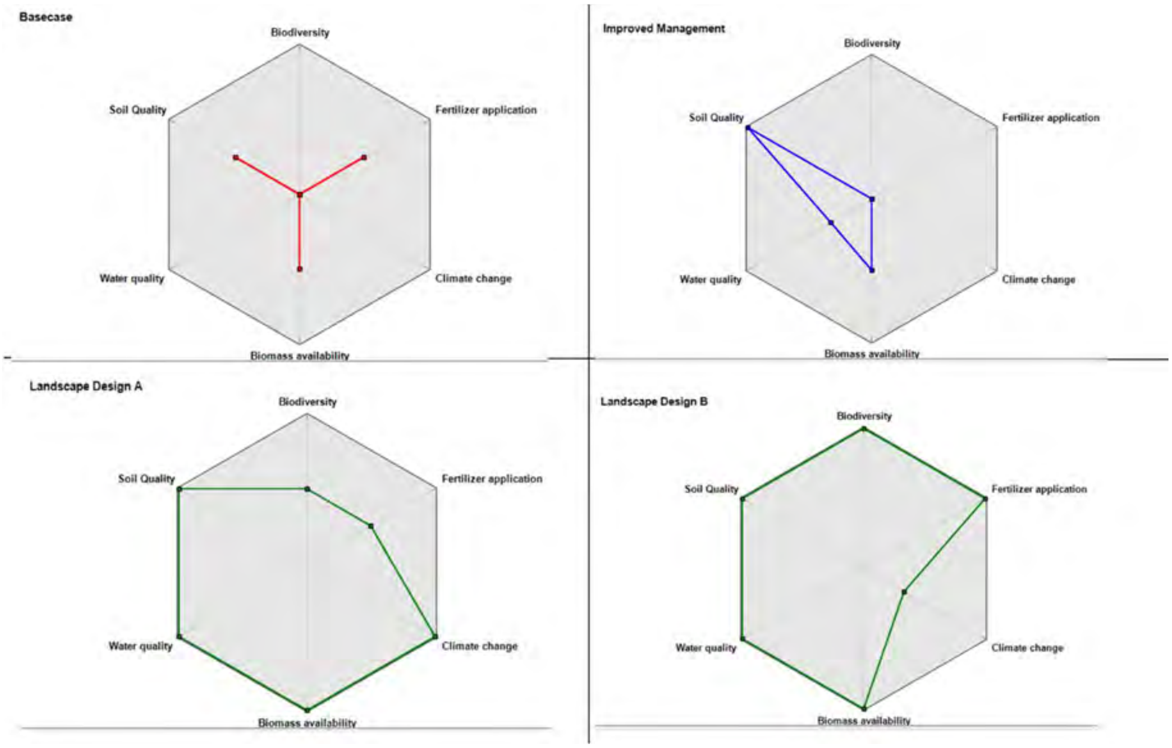

Basecase

Improved Management

Landscape Design A

Landscape Design B

Figure 4. Indicator tradeoffs and overall sustainabilty for each of the four landscape design scenarios at the Nevada Fuelshed extent.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Landscape Design B

Figure 5. Indicator tradeoffs and overall sustainabilty for each of the four landscape design scenarios at the South Fork Watershed extent.

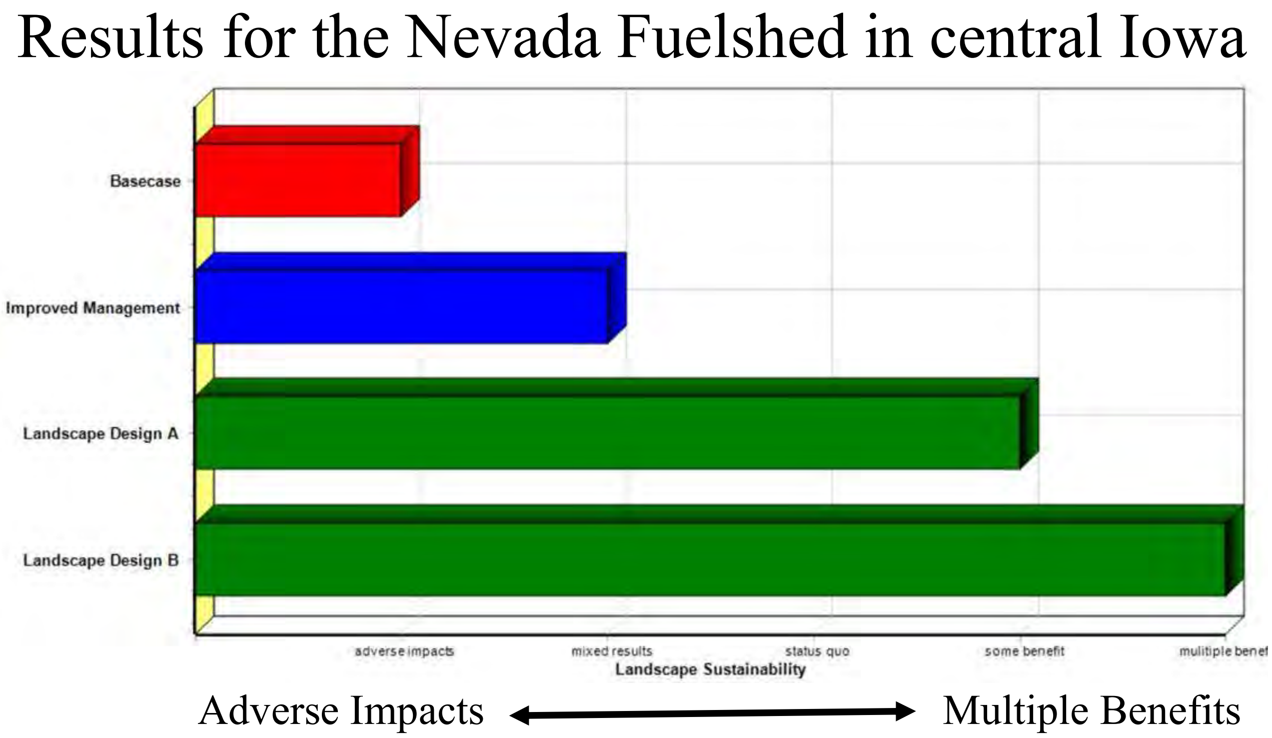

Figure 6. Comparison of relative sustainability for the four alternative landscape design scenarios at the Nevada Fuelshed extent.

Key results and important recommendations for future landscape design projects based on this research and extensive stakeholder feedback to date include:

- Landscape designs which incorporate perennial grass plantings and corn stover removal for bioenergy production can result in multiple benefits for stakeholders, including:
  - increasing biodiversity (e.g., bird populations) through addition of grassland acres to the landscape (see Case Study 3),
  - improving soil quality through augmentation of the soil conditioning index (see Case Study 10) and/or reducing wind and water erosion (see Case Study 6),
  - cost savings from reduced fertilizer applications,
  - improved water quality related to reduced nitrate leaching,
  - climate change mitigation through increased sequestration of carbon within the soil, and
  - increased biomass feedstock availability for fuel and other uses without significant changes in corn grain food production volumes (see Case Study 2).
- It is possible to achieve multiple environmental and socioeconomic benefits concomitantly with increased cellulosic biomass production by targeting the 10% of traditional row crop land that has historically shown the lowest profitability (see Case Study 1).
- Increasing benefits can accrue when complementary conservation practices (e.g., reduced tillage, use of a rye cover crop—described in Case Study 9) are combined and integrated throughout a watershed based on site-specific criteria and goals for landscape design.

> Realizing the potential benefits from landscape design depends on appropriate market incentives and the transfer of reliable information on costs and benefits to land managers.

References

Dale, V. H., Kline, K. L., Richard, T. L., Karlen, D. L., and Belden, W. W. 2018. Bridging biofuel sustainability indicators and ecosystem services through stakeholder engagement. Biomass and Bioenergy 114:143-156. https://doi.org/10.1016/j.biombioe.2017.09.016

Dale, V.H., Kline, K.L., Parish, E. S, and Eichler, S.E. 2019. Engaging stakeholders to assess landscape sustainability: Experiences and insights. Landscape Ecology. DOI: 10.1007/s10980-019-00848-1. https://rdcu.be/bHFGF

Parish ES, Dale VH, English BC, Jackson SW, Tyler DD. 2016. Assessing multimetric aspects of sustainability: Application to a bioenergy crop production system in East Tennessee. Ecosphere 7(2):e01206. https://doi:10.1002/ecs2.1206

No. 8. Sustainable Corn Stover Harvest: The Foundation for this Landscape Design Project

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Corn stover, the aboveground plant material left in fields after grain harvest, was identified as a sustainable biofuel feedstock for the U.S. in the Billion Ton Report (Perlack et al., 2005). Factors contributing to its appeal as a biofuel feedstock include the global scale of production, relative abundance in high-yielding agricultural fields, and unlike grain, stover does not compete with food production. However, stover biomass is not a waste and must be managed in a sustainable manner. Stover has several uses and provides many ecosystem benefits including: (i) use for animal feed and bedding, (ii) protection of soils from wind and water erosion, (iii) conservation of soil water by reducing evaporation losses, (iv) reducing soil surface temperature, and (v) maintaining soil organic carbon (SOC) levels. To achieve a balance among those multiple potential uses, stover harvest rates must be sustainable and only occur in areas where available amounts can provide for all site-specific uses. The need for long-term, ecological balance makes corn stover harvest an ideal foundation for sustainable Midwestern U.S. landscape designs.

This landscape design project began to evolve at least seven years before it was implemented in 2015. At that time, several USDA-Agricultural Research Service (ARS) and Department of Energy (DOE) engineers from the DOE Idaho National Laboratory (INL) were collaborating through a Sun Grant Regional Project (Initiative, 2020) to provide field validation data regarding long-term effects of corn stover harvest for the Billion Ton Report. Several stover harvest rates, methods, and management strategies (e.g., reduced tillage intensity, cover crops, inter-cropping, crop rotations, biochar applications) were evaluated using various soil health and sustainability indicators in seven states by USDA, DOE, university, and private-sector collaborators. The goal was to balance the need to provide bioenergy and bio-product supply chains with a steady, reliable, high-quality feedstock with the multiple ecosystem service needs for crop residues (i.e., corn stover) as illustrated in Figure 1 from Wilhelm et al (2010).

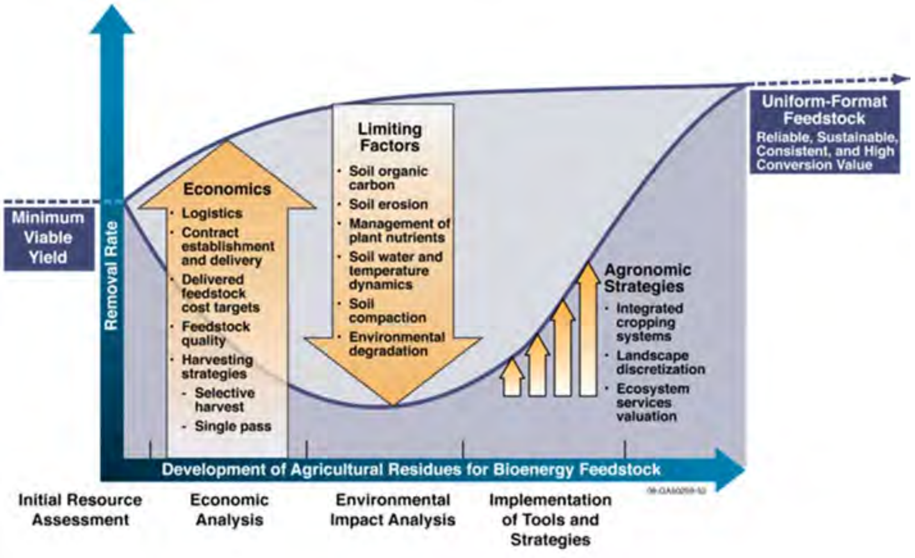

Figure 1. Landscape design strategies can balance economic and conservation goals.

Based on an ecosystem services perspective (Wilhelm et al., 2007; Johnson et al., 2014) and to implement soil conservation recommendations from mentors such as Dr. William E. Larson, who often referred to soil as "the thin layer covering the planet that stands between us and starvation," the corn stover harvest studies emphasized the impact on soil carbon (organic matter). If stover harvest threatened to deplete soil carbon stocks, it simply should not be implemented. However, by increasing crop yield, developing balanced nutrient management plans, and increasing the amount of photosynthetically derived (fixed) carbon returned to the soil each year, a sustainable amount of corn stover might be harvestable (Johnson et al., 2006). The multi-state project (Karlen et al., 2014) explored multiple ways to achieve those goals, including cropping system changes, reduced tillage, and application of biochar, all which could become integral parts of sustainable, integrated landscape designs. Furthermore, it is important to recognize that soil and crop management choices can not only be part of the problem, but also result in positive changes soil health and resilience changes as illustrated in Figure 2.

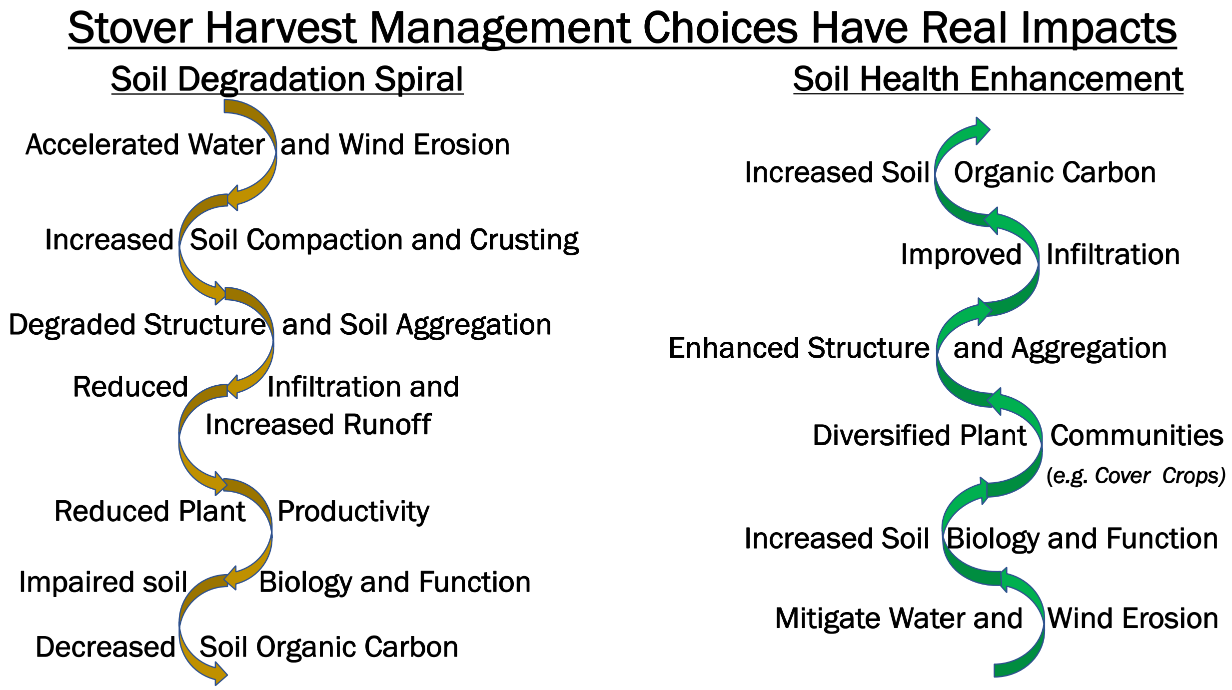

Figure 2. Stover harvest effects can be positive or negative depending on human decisions.

Management choices that denude the soil through excessive tillage, overly aggressive residue harvest, mono-or low diversity crop rotations, or uncontrolled high axle-load wheel traffic are just some of the choices that have and continue to put agricultural lands at risk. Fortunately, we also have choices that can build healthy resilient soils, capable of meeting society's need for food, fiber, feed and fuel, as well as other agroecosystem services. These management choices exist at field, farm and landscape scales and must be balanced to achieve long-term goals.

The initial corn stover harvest studies led the team to conclude that for long-term economic and environmental sustainability, landscapes rather than fields needed to be the focus and scale for research if it was to provide guidance for science-based decisions and policies that would meet both DOE bio-refinery and USDA soil conservation goals. Striving for a sustainable, site-specific balance would also address many other social issues being debated at that time. Therefore, a conceptual framework for landscape design was presented at an American Association for Advancement of Science (AAAS) symposium focused on the Food vs Fuel debates (Hess et al. 2010).

Leveraging work from the USDA-Agricultural Research Service Cross location efforts of REAP (Resilient Economic Agricultural Practices), augmented through the Sun Grant Regional Project, and subsequent corn stover harvest studies associated with this Landscape Design project, we provided six important guidelines for sustainable corn stover harvest (Johnson et al., 2010). They are:

1. Do not harvest stover if the field has unabated wind- or water-induced soil erosion or classified as highly erodible.
2. Do not harvest stover without having recent (3 to 5 year) soil-test and plant nutrient management records for the potential harvest sites. These records are critical to establish a soil carbon (organic matter) baseline and to be aware of any potential nutrient limits such as low soil-test potassium (K) levels.
3. If full-width tillage and seedbed preparation practices (e.g., chisel plowing and field cultivation) are being used for continuous corn production, do not harvest stover unless annual corn grain yields average 190 bu ac^{-1} (12 Mg ha^{-1}) or more.
    a. Low to moderate annual stover harvest (1.5 to 3 tons ac^{-1}) is better management option compared to tillage as strategy to limit the tillage induced release stored soil carbon.
4. For corn-soybean rotations with consistent corn grain yields of 175 bu ac^{-1} (11 Mg ha^{-1})[1], low stover harvest rates (1 to 2 tons ac^{-1}) can often be taken provided soil-test values continue to be monitored and show no adverse soil carbon or nutrient decreases.
5. Incorporating cover crops and reducing tillage frequency and intensity will often enable stover harvest rates to be increased slightly but total removal should never exceed 50%.
6. Whenever feasible, site-specific, sub-field management practices with differential stover harvest rates should be implemented.
    a. These types of landscape design strategies enable incorporation of buffer strips, pollinator crops, and contour-based crop rotations rather than continuing uniform management across multiple soil types and slopes.

References

Hess, J. R., J. J. Jacobson, D. L. Karlen, D. J. Muth Jr., R. G. Nelson, L. P. Ovard, E. M. Searcy, and T. H. Ullrich. 2010. Agriculture and land use issues. p. 86-115. *In*: Rosillo-Calle, F. and Johnson, F. X. (eds.), Food versus Fuel: An Informed Introduction to Biofuels. Zed Books Ltd., London, UK.

Initiative, Sun Grant. 2020. "Sun Grant Initiative: The First Fifteen Years". Sun Grant Initiative Publications and Reports. 1. https://openprairie.sdstate.edu/ncrsgc_pubs/1

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[1] For Case Study 7, acres were considered suitable for harvesting 30 or 45% of the corn stover if they had an average yield of ≥ 165 bu/acre (for 2013-2016) and slopes ≤ 5%.

Johnson J. M. F., R. R. Allmaras R.R., and D. C. Reicosky. 2006. Estimating source carbon from crop residues, roots and rhizodeposits using the national grain-yield database. Agronomy Journal 98:622-636. doi:10.2134/agronj2005.0179.

Johnson J. M. F., D. Reicosky, R. Allmaras, D. Archer, and W. Wilhelm. 2006. A matter of balance: Conservation and renewable energy. Journal of Soil and Water Conservation 61:120A-125A.

Johnson J. M. F., D. L. Karlen, and S. S. Andrews. 2010. Conservation considerations for sustainable bioenergy feedstock production: If, what, where, and how much? Journal of Soil and Water Conservation 65:88A-91A. doi:10.2489/jswc.65.4.88A.

Johnson, J. M. F., J. M. Novak, G. E. Varvel, D. E. Stott, S. L. Osborne, D. L. Karlen, J. A. Lamb, J. Baker, and P. R. Adler. 2014. Crop residue mass needed to maintain soil organic carbon levels: Can it be determined? BioEnergy Research. 7:481-490.

Karlen, D. L., S. J. Birrell, J. M. F. Johnson, S. L. Osborne, T. E. Schumacher, G. Varvel, R. B. Ferguson, J. M. Novak, J. R. Fredrick, J. Baker, J. A. Lamb, P. R. Adler, G. W. Roth, and E. D. Nafziger. 2014. Multilocation corn stover harvest effects on crop yields and nutrient removal. BioEnergy Research. 7:528-539.

Perlack, R. D., L. L. Wright, A. F. Turhollow, R. L. Graham, B. J. Stokes, and D. C. Erbach. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply. DOE/GO-102005-2135 and ORNL/TM-2005/66.https://www.researchgate.net/publication/235205302_Biomass_as_Feedstock_for_A_Bioenergy_and_Bioproducts_Industry_The_Technical_Feasibility_of_a_Billion-Ton_Annual_Supply (accessed 18 September 2020).

Wilhelm, W. W., J. M. F. Johnson, D. L. Karlen, and D. T. Lightle. 2007. Corn stover to sustain soil organic carbon further constrains biomass supply. Agronomy Journal. 99:1665-1667.

Wilhelm W.W., J. R. Hess, D. L. Karlen, J. M. F. Johnson, D. J. Muth, J. M. Baker, H. T. Gollany, J. M. Novak, D. E. Stott, and G. E. Varvel. 2010. REVIEW: Balancing limiting factors & economic drivers for sustainable Midwestern US agricultural residue feedstock supplies. Industrial Biotechnology 6:271-287. doi:10.1089/ind.2010.6.271.

No. 9. Cover Crops: A First Step Toward Landscape Design and Increased, Sustainable Cellulosic Feedstock Supplies

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Cover cropping has received major national attention during the past decade because of their potential ability to provide multiple conservation benefits including reduced soil erosion, decreased soil organic carbon (SOC) decline or even SOC increases through C sequestration. Therefore, including cover crops in landscape design strategies to increase bioenergy feedstock supplies, enhance soil health, and protect water quality may be a relatively easy for farmers to implement. Recognizing several opportunities to leverage cover crop studies being led by the USDA Natural Resources Conservation Service (NRCS), National Corn Growers Association (NGCA), American Soybean Association (ASA), Conservation Technology Information Center (CTIC), Midwest Cover Crop Association, and other groups, preliminary studies were conducted to evaluate how cover crops could be used to increase cellulosic feedstock supplies.

Plot-scale studies were conducted in Boone County Iowa to quantify effects of a winter rye cover crop on soil health indicators, productivity of subsequent soybean and corn crops, and potential amount of cellulosic biomass that could be harvested in lieu of killing the cover crop prior to planting soybean. An on-farm study was also conducted to determine if planting cover crops after harvesting corn stover would have detectable effects on surface runoff and nutrient loss.

A field study evaluating corn stover harvest, tillage, and cover crop effects on soil health indicators showed growing cover crops had the potential to increase mineralizable N within no-till continuous corn production systems (Obrycki et al., 2018). Meanwhile, a simulation model study with RZWQM (Root Zone Water Quality Model) indicated that a spring application of 120 kg N ha^{-1} to winter rye that was planted as a cover crop following corn and then harvested for biomass before planting soybean could reduce drainage N loss by 54% compared to having no cover crop. Fertilizing and harvesting the winter rye cover crop was also estimated to reduce N drainage losses by 18% when compared with a rye cover crop that was neither fertilized nor harvested (Malone et al., 2018). Additional RZWQM estimates indicated a positive net energy balance and increased producer revenue based on harvesting 8.3 Mg ha^{-1} of rye biomass. New cover crop studies to verify those projections have been initiated by ARS, Iowa State University (ISU) and Pennsylvania State University (PSU) scientists and engineers. Those studies are not directly connected to this Landscape Design project but represent leveraging project fostered.

Potential Landscape Design applications for cover crops were evaluated at two sites (Field 70/71 and Field 78/79) in Boone County Iowa, USA. Six of 22 cropping system treatments in Field 70/71 had cover crops incorporated into the rotation. Winter rye was over-seeded into corn before harvesting grain and approximately 35 or 60% of the aboveground stover biomass. The rye cover crop was allowed to grow until early June (6/02/15, 6/08/16, 6/01/17, 6/06/18, and 6/10/19). It was then harvested prior to planting soybean, which by that time was about four weeks after what is defined as the optimum planting date for central Iowa. One of the most important factors affecting eventual grain yield response of the soybean crop was the June rainfall. Above average rainfall further delayed planting and slowed early season growth while very low June rainfall resulted in erratic germination and also slowed plant growth.

Physiologically, soybean has an ability to compensate for slow early-season growth, especially by indeterminant varieties grown in Iowa. Table 1 presents rye biomass, average soybean plot yields, and the National Agricultural Statistics Service (NASS) Boone County average soybean yield for 2015 through 2019. The average rye dry biomass production was 1.60 tons/acre (3.60 Mg ha^{-1}), while average plot and county-level soybean yields were 50.5 and 55.7 bu/acre, (3.38 and 3.74 Mg ha^{-1}), respectively.

Table 1. Rye biomass, soybean plot yield, and Boone County Iowa average soybean yield throughout this Landscape Design study.

Year	Rye biomass (t/ac)	Soybean plot yield (bu/ac)	Boone County Yield (bu/ac)	Average Soybean Price ($/bu)	June Precipitation (mm)
2015	1.56	64.4	53.7	8.91	175
2016	2.09	44.8	60.2	9.34	25
2017	1.58	46.8	56.7	9.25	44
2018	0.92	41.2	54.6	8.46	282
2019	1.87	55.1	53.2	8.48	98
Average	1.60	50.5	55.7	8.89	125

Recognizing that delayed soybean plant would result in a grain yield loss, we computed a break-even minimum value that rye biomass would have to be sold at to compensate for a 5.2 bu ac^{-1} reduction in grain yield. Using a five-year average soybean price of \$8.89 bu^{-1}, rye biomass would have to be sold for no less than \$28.92 ton^{-1} to break even without adding additional equipment, time, or other harvest, storage, or transportation expenses. The results were quite promising, however, since rye forage could be expected to sell for ~\$50 ton^{-1} in most areas. Furthermore, by harvesting the cover crop, there was no need for a burn-down herbicide application in addition to that applied for weed control in the subsequent soybean crop.

A winter rye cover crop was also over-seeded into corn plots on Field 78/79 which was managed in a corn-soybean rotation using strip tillage to prepare the seedbed. Rye for those treatments was killed with herbicide prior to planting soybean the next year. A third crop rotation with cover crop treatment incorporated into the experimental design for Field 70/71 plots was to grow wheat following the soybean crop and then planting a mixture of radish, oat, and peas that were grown until early November before harvesting it as a potential animal feed. Those results were much more exploratory and have not been included in this report.

A third Ames-based cover crop study was designed to expand plot-scale studies from Field 70/71 to an on-farm production-scale project on a farm located about 50 miles northeast of Ames, IA. Our goals implemented on ~60 acres were to: (i) determine how time-consuming and difficult implementation might be; (ii) assess producer risk; and (iii) consider seeking a Farm Service Agency (FSA) conservation research program waiver to help protect the financial security of our farmer cooperator. The study (Figure 1) was implemented on a field site with two sub-basins that had been monitored by the ARS to quantify runoff, erosion, and nutrient loss for nearly ten years. Two replicates comparing corn stover harvest using a rake and bale collection operation following grain harvest with either the producer's combine and standard head or with moderate and high removal using a Streater Corn-Rower™ head (Figure 2). Although the intent had been to over-seed the winter rye cover crop before corn grain harvest and several options were pursued to accomplish that goal, but inclement weather and scheduling delays prevented early planting of the cover crop each year. Therefore, it was not planted until after corn grain harvest, which slowed emergence and fall growth such that plans for a spring harvest were dismissed.

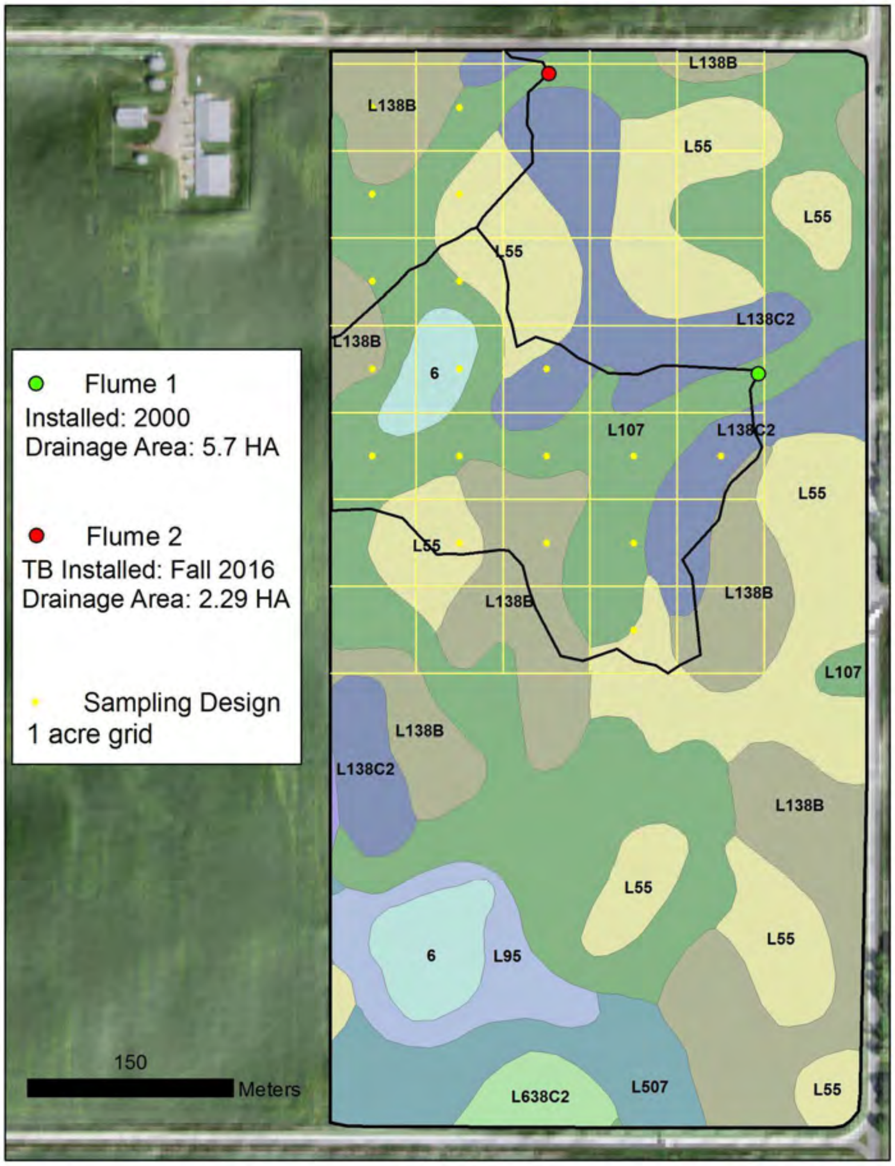

Figure 1. Sub-basin watershed layout and dominant soil map units at the Kadolph farm. Cover crops were planted into the lower basin but not into the upper one. Runoff differences were minimal because of poor rye growth.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 2. On-farm stover harvest layout prior to planting a rye cover crop in Central Iowa, USA.

We remain optimistic regarding the potential to incorporate cover crops into Midwest Landscape Designs and thus enhance soil health, producer income, water quality and provide another source of sustainable feedstock for bioenergy production.

References

Malone, R. W., J. F. Obrycki, D. L. Karlen, L. Ma, T. C. Kaspar, D. B. Jaynes, T. B. Parkin, S. H. Lence, G. W. Feyereisen, Q. X. Fang, T. L. Richard, and K. Gillette. 2018. Harvesting fertilized rye cover crop: Simulated revenue, net energy, and drainage nitrogen loss. Agricultural and Environmental Research Letters 3:170041. doi:10.2134/ael2017.11.0041

Obrycki, J. F., D. L. Karlen, C. A. Cambardella, J. L. Kovar, and S. J. Birrell. 2018. Corn stover harvest, tillage, and cover crop effects on soil health indicators. Soil Science Society of America Journal 82:910-918. doi:10.2136/sssaj2017.12.0415

No. 10. Baseline Soil Health Assessment of CRP Conversion in Central Iowa, USA

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BACKGROUND

A core component of this Landscape Design Assessment Project (LDAP) was to establish soil health indicator baselines to quantify soil resource impacts of future landscape design projects that incorporate perennial grass-based bioenergy feedstock production systems.

To accomplish that goal, we evaluated soil health indicators in 38 fields on 18 private farms in central Iowa using renewals and conversions to the Conservation Reserve Program (CRP) as a proxy for perennial grass bioenergy systems. Landowners participating in this research were enrolled in the CP-38 Pheasant Recovery program which is one component of CRP. To emulate perennial grass-based bioenergy production systems, seed mixtures for CP-38 were modified to maximize switchgrass [*Panicum virgatum* (L.)] composition. We compared converted fields to adjacent fields managed using business-as-usual (BAU) row-crop or managed pasture practices.

FIELD SELECTION

Farms were selected so that CRP sites could be paired with adjacent, on-going BAU fields with similar soils and topographic characteristics. The resulting fields spanned a range of land use intensities, where the least intensive use was represented by fields historically managed as CRP (i.e., no agrochemical inputs, no soil physical disturbance, limited machine passes, and limited biomass removal). The most intensive land use was represented by row-crop agriculture (i.e., use of agrochemical inputs, grain removal, and multiple agricultural equipment operations) as shown in Figure 1. It is important to note that all CRP-old fields were re-enrolled into the CP-38 program in 2017-2018 for this LDAP study. This required chemically killing existing CRP vegetation and reseeding with the CP-38 seed mix using a no-till drill. The CRP-new fields were converted in 2017-2018 from either long-term pasture or long-term row-crop production. The BAU-pasture and BAU-crop fields had been managed conventionally (i.e., grazing, fertilizer use in pastures; tillage, fertilizer use in row-crops) for at least eight years prior to soil sampling. In

	Native	Old CRP (10-40 yr)	Pasture	New CRP (<1 yr)	Row-crop
# Fields	0	12	9	6	11

Figure 1. Number of LDAP study fields representing various levels of land use intensity.

addition to management effects, we also compared two different slope classes (lower *vs.* higher slope) within each field to evaluate whether use of perennial grasses enhanced soil health to a greater degree in parts of the field that were more environmentally sensitive (i.e., higher sloping).

SOIL SAMPLING AND ANALYSES

Soil health indicator samples representing both CRP and BAU treatments were collected in April/May of 2018. At each location, soil samples were collected from CRP and BAU sites at two landscape positions with higher (13 to 25%) and moderate (7 to 13%) slopes. Samples were collected at both landscape positions within a field (Figure 2) to a depth of 120 cm and separated into six depth increments (0 to 5-, 5 to 15-, 15 to 30-, 30 to 60-, 60 to 90-, 90 to 120-cm). In addition to deep soil cores, surface soils were sampled with a flat-edged spade for 0 to 5- and 5 to 15-cm depth increments to quantify wet and dry soil aggregate properties (see below). Soil health assessments were made using the Soil Management Assessment Framework (SMAF) for the 0 to 5- and 5 to 15-cm depth increments.

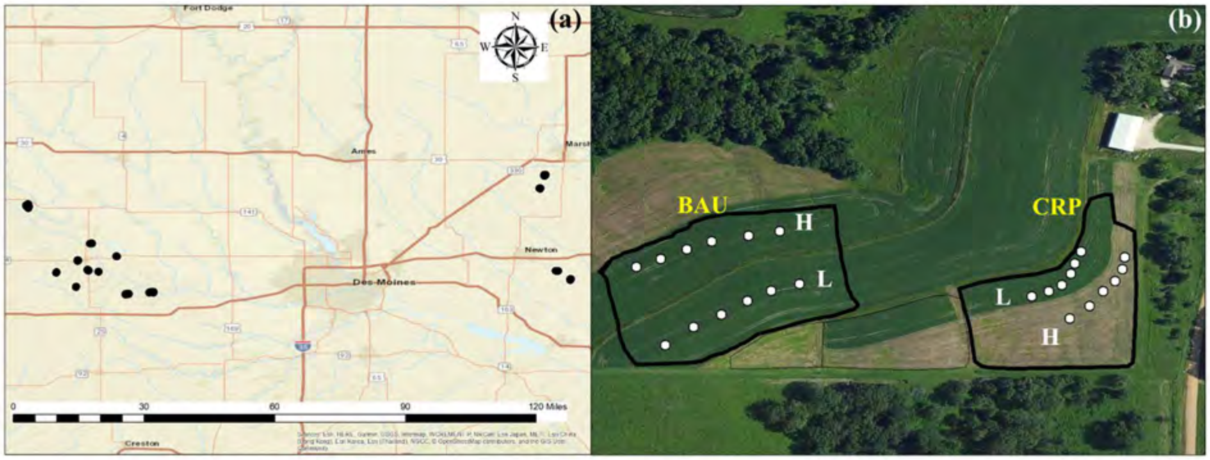

Figure 2. Iowa sampling sites (a) and typical collection pattern (b).
BAU: business as usual; CRP: conservation reserve program; H: high slope (13 to 25%); L: low or moderate slope (7 to 13%).

Soil samples were analyzed for eight soil health indicators, six using deep core samples [bulk density (BD), pH, electrical conductivity (EC), soil organic carbon (SOC), β-glucosidase activity (BG), plant-available phosphorus (P), and plant-available potassium (K)] and two using spade samples [water-stable aggregate (AGG) and dry aggregate size distribution]. Soil texture was determined to help classify the soils and select appropriate SMAF factors for assessing soil management effects.

SOIL HEALTH ASSESSMENT AND STATISTICAL ANALYSES

Eight of the soil health indicator measurements were used to create a minimum data set for the SMAF analysis. This tool can be used to assess productivity, environmental, or other effects and thus provides a standardized approach for determining soil quality (soil health). We used it for evaluations in the context of crop growth. For this analysis, the SMAF indicators were divided into four groups describing soil physical, chemical, nutrient, and biological soil health characteristics. The user identifies a minimum data set (MDS) which includes indicators that represent each of the four categories. The individual indicators that make up each category are assigned a soil health score based on soil indicator response curves that are sensitive to soil texture class, mineralogy, methods of analysis, sampling time and other factors (Figure 3).

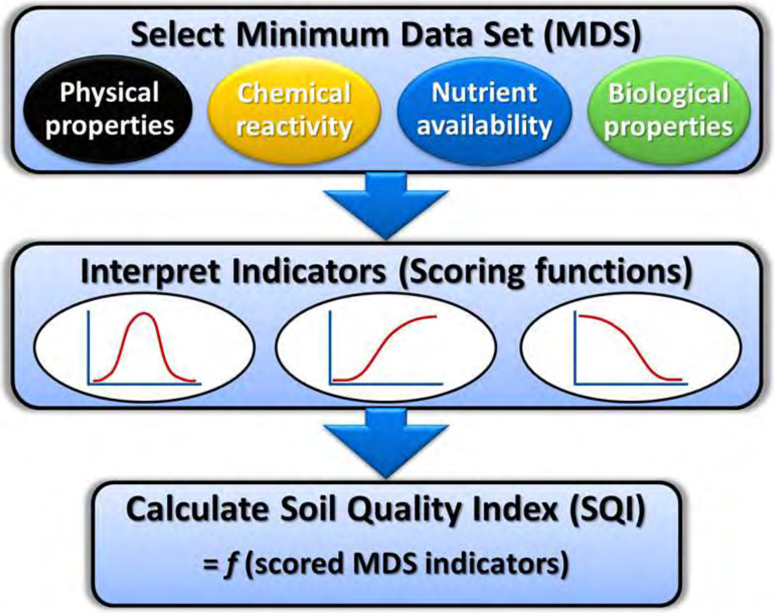

Figure 3. Description of the Soil Assessment Framework inputs and outputs.

Scoring curves may be represented by: (1) a bell-shaped curve, where a maximum score indicates an optimum value (pH, P); (2) an increasing curve, indicating a "more-is-better" function (AGG, SOC, BG, K); or (3) a decreasing curve, indicating a "less-is-better" function (BD, EC). Although a recent study indicated that the current scoring curves might underestimate SOC and BG and likely result in lower scores (Nunes et al., 2020), SMAF results and interpretation here are based on the current SMAF algorithms because updated scoring curves are not available yet. When individual health scores are added together within a category, a Soil Quality Index (SQI) for that specific category can be calculated. All indicator scores can then be added together to compute an overall SQI value (Andrews et al., 2004; Wienhold et al., 2009). The SQI values range from 0.0 to 1.0, with higher values in our analysis considered better for crop growth. The overall SQI presented below reflect the eight indicators we measured in the 0 to 15-cm depth increment.

A two-way mixed model of analysis of variance was used to evaluate management, topography and the interaction effects. Management and topography were defined as fixed factors while replicate was considered to be a random factor. Structural equation modeling was conducted to quantify effects of management and topography on SMAF scores and to illustrate how the variables interacted with each other to produce the overall effect. Structural equation modeling quantifies effects by generating standardized effect sizes ranging from 0 to 1.

RESULTS

Eight potential soil health indicators were summarized by management practice across the 18 Iowa locations using the Soil Management Assessment Framework (SMAF) for analysis. The indicators were water-stable macroaggregate percentage (AGG), bulk density (BD), pH, electrical conductivity (EC), soil organic carbon (SOC), β-glucosidase activity (BG), phosphorus (P), and potassium (K). The Management practices were defined as: BC, business as usual-crop; BP, business as usual-pasture; CO, conservation reserve program-old; and CN, conservation reserve program-new. The results are reported as mean ± standard error values with different letters following each factor to indicate significant differences at the $p < 0.05$ level. Table 2

Table 1. Main effects of management and slope on soil health indicator data for input into SMAF

	Management				Slope	
Level	BC	BP	CN	CO	Higher	Lower
AGG (%)	53.0 ± 0.63 (d)	71.6 ± 0.70 (b)	58.4 ± 0.93 (c)	74.3 ± 0.58 (a)	59.1 ± 0.38 (b)	69.1 ± 0.38 (a)
BD (g cm^{-3})	1.27 ± 0.03 (a)	1.17 ± 0.03 (bc)	1.26 ± 0.04 (ab)	1.13 ± 0.02 (c)	1.22 ± 0.02 (a)	1.20 ± 0.02 (a)
pH (1:1 water)	5.88 ± 0.12 (b)	6.21 ± 0.13 (ab)	6.16 ± 0.17 (ab)	6.38 ± 0.11 (a)	6.16 ± 0.08 (a)	6.15 ± 0.07 (a)
EC (dS m^{-1})	0.38 ± 0.02 (a)	0.34 ± 0.02 (ab)	0.35 ± 0.03 (ab)	0.30 ± 0.02 (b)	0.35 ± 0.01 (a)	0.34 ± 0.01 (a)
SOC (%)	1.74 ± 0.13 (b)	2.30 ± 0.15 (a)	1.74 ± 0.19 (b)	2.28 ± 0.12 (a)	1.92 ± 0.08 (b)	2.11 ± 0.08 (a)
BG (mg nitrophenol kg^{-1} hr^{-1})	101.4 ± 7.7 (b)	150.8 ± 8.5 (a)	107.5 ± 11.4 (b)	144.9 ± 7.2 (a)	122.6 ± 5.1 (a)	129.7 ± 5.1 (a)
P (ppm)	22.9 ± 2.5 (a)	13.0 ± 2.7 (bc)	21.9 ± 3.7 (ab)	9.9 ± 2.3 (c)	15.1 ± 1.7 (a)	18.7 ± 1.7 (a)
K (ppm)	170 ± 19 (b)	243 ± 21 (a)	190 ± 28 (ab)	238 ± 18 (a)	190 ± 13 (b)	230 ± 13 (a)
Sand (%)	17.9 ± 1.8	20.4 ± 2.0	17.3 ± 2.6	22.2 ± 1.6	20.1 ± 1.1	18.9 ± 1.1
Silt (%)	49.2 ± 1.7	47.7 ± 1.9	51.2 ± 2.6	46.0 ± 1.6	48.2 ± 1.1	48.8 ± 1.1
Clay (%)	32.9 ± 0.7	31.8 ± 0.8	31.5 ± 1.0	31.9 ± 0.6	31.7 ± 0.5	32.3 ± 0.5

Table 2 Main effects of management and slope on soil health scores

Factor	Management				Slope	
Level	BC	BP	CN	CO	Higher	Lower
Overall SQI	0.70 ± 0.02 (a)	0.74 ± 0.02 (a)	0.73 ± 0.02 (a)	0.72 ± 0.01 (a)	0.72 ± 0.01 (a)	0.73 ± 0.01 (a)
Physical SQI	0.79 ± 0.02 (c)	0.90 ± 0.03 (ab)	0.82 ± 0.04 (bc)	0.93 ± 0.02 (a)	0.86 ± 0.01 (a)	0.86 ± 0.01 (a)
Chemical SQI	0.94 ± 0.01 (ab)	0.95 ± 0.02 (ab)	0.91 ± 0.02 (b)	0.98 ± 0.01 (a)	0.95 ± 0.01 (a)	0.95 ± 0.01 (a)
Biological SQI	0.19 ± 0.03 (b)	0.35 ± 0.04 (a)	0.23 ± 0.05 (ab)	0.32 ± 0.03 (a)	0.27 ± 0.02 (a)	0.27 ± 0.02 (a)
Nutrient SQI	0.85 ± 0.04 (ab)	0.77 ± 0.04 (bc)	0.93 ± 0.06 (a)	0.67 ± 0.04 (c)	0.77 ± 0.03 (b)	0.85 ± 0.03 (a)
AGG score	0.96 ± 0.003 (a)	1.00 ± 0.004 (a)	1.00 ± 0.005 (a)	1.00 ± 0.003 (a)	0.98 ± 0.003 (a)	1.00 ± 0.003 (a)
BD score	0.62 ± 0.05 (c)	0.79 ± 0.05 (ab)	0.65 ± 0.07 (bc)	0.87 ± 0.04 (a)	0.73 ± 0.03 (a)	0.73 ± 0.03 (a)
pH score	0.89 ± 0.03 (ab)	0.91 ± 0.03 (ab)	0.83 ± 0.04 (b)	0.96 ± 0.03 (a)	0.89 ± 0.02 (a)	0.90 ± 0.02 (a)
EC score	1.00 ± 0.00 (a)	1.00 ± 0.00 (a)	1.00 ± 0.00 (a)	1.00 ± 0.00 (a)	1.00 ± 0.00 (a)	1.00 ± 0.00 (a)
SOC score	0.29 ± 0.05 (b)	0.52 ± 0.06 (a)	0.35 ± 0.08 (ab)	0.48 ± 0.05 (a)	0.40 ± 0.03 (a)	0.42 ± 0.03 (a)
BG Score	0.09 ± 0.01 (c)	0.18 ± 0.02 (a)	0.11 ± 0.02 (bc)	0.15 ± 0.01 (ab)	0.14 ± 0.01 (a)	0.13 ± 0.01 (a)
P score	0.78 ± 0.07 (ab)	0.57 ± 0.08 (b)	0.89 ± 0.11 (a)	0.35 ± 0.07 (c)	0.57 ± 0.05 (b)	0.72 ± 0.05 (a)
K score	0.93 ± 0.01 (b)	0.97 ± 0.01 (a)	0.97 ± 0.02 (a)	0.98 ± 0.01 (a)	0.96 ± 0.01 (a)	0.97 ± 0.01 (a)

presents the scores for each indicator. Those values were used to calculate categorical and overall SQI values.

<u>Management effects</u>

Across the four management scenarios (BAU-crop, BAU-pasture, CRP-old, and CRP-new), overall SQI values ranged from 0.70 ± 0.02 to 0.74 ± 0.02 (Figure 4). Based on inherent soil and climate characteristics, this indicates the soil was functioning at 70 to 74% of its theoretical potential. Conversion from cropland to CRP increased the overall SQI by 4.2% by increasing physical, biological, and nutrient SQIs. Specifically, CRP-old had significantly higher indicator scores for BD (39%), AGG (3.7%), SOC (63%), BG (71%), and K (5.7%) compared to BAU-crop (Figures 4 and 5). Increased length of time under CRP positively affected soil physical, chemical, and nutrient SQIs. Compared to CRP-new, CRP-old sites had significantly higher scores for BD (34%) and pH (16%) scores but lower plant-available P (61%) scores. Additionally, land use intensity affected physical, biological, and nutrient SQIs. The BAU-pasture had significantly higher scores for BD (27%), SOC (77%), BG (99%), and K (4.7%) compared to BAU-crop. The constant EC score of 1.00 across all treatments and for both slope groups confirms (as expected) that salinity is not a problem at these Iowa sites.

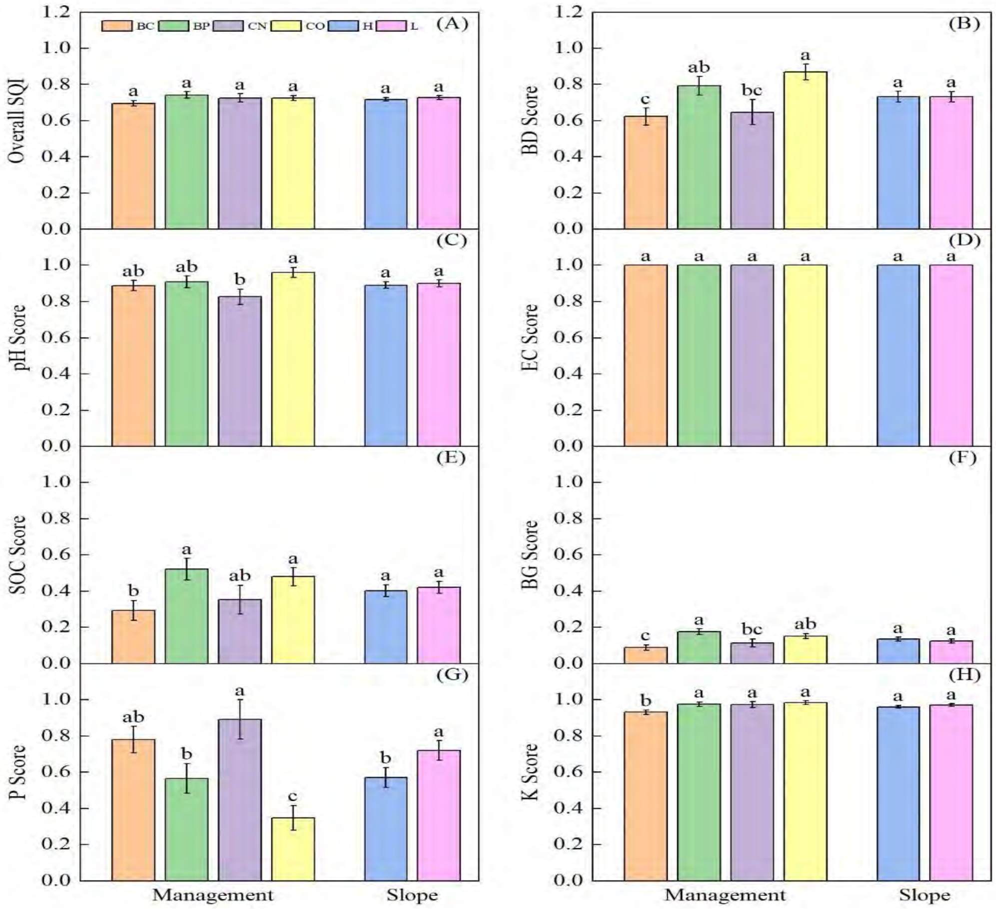

Figure 4. Overall and component soil quality index (SQI) values for CRP vs BAU management and slope designations of low (7 to 13%) or high (13 to 25%). Bars indicate standard errors, while different letters after each factor indicate significant differences at a $p < 0.05$ level.

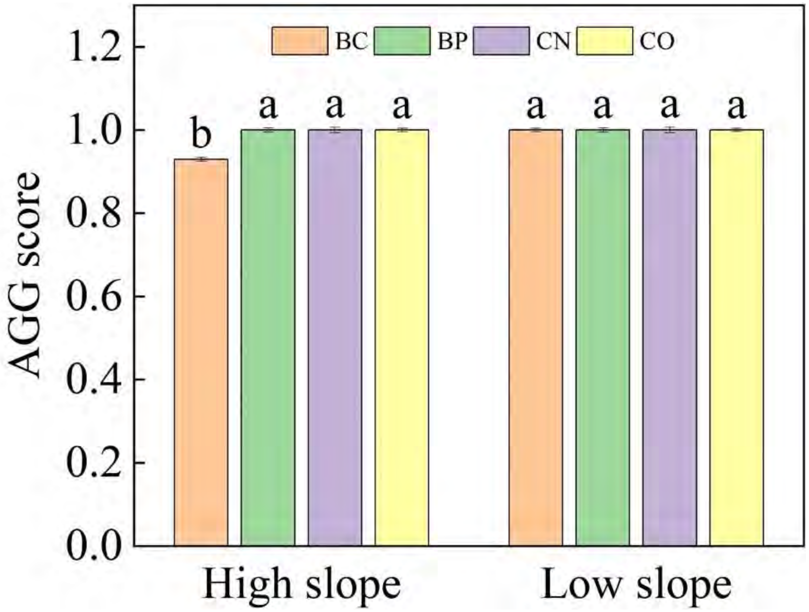

Figure 5. Water-stable aggregate (AGG) scores for CRP or BAU management at high and low slope positions. Bars indicate standard errors, while different letters after each factor indicate significant differences at a $p < 0.05$ level.

Slope effects

As a single factor, slope position significantly affected only plant-available P scores ($p = 0.03$). The P scores were higher at lower slope positions (7 to 13%) than at higher slope (13 to 25%) sites, presumably due to historical downslope transport of dissolved P or P associated with soil particles in runoff or erosion.

Interaction effects of management and slope

An important indicator of soil physical health is soil aggregation. Aggregate formation a key process in physically stabilizing soils against erosion as well as in storing soil organic carbon (Tisdall and Oades, 1982; Six et al., 2000). The soil's aggregate size distribution describes the degree of soil aggregation by size classes, where microaggregates typically defined as <0.053-0.25 mm, macroaggregates as 0.25-2 mm (Golchin et al., 1994), and mega-aggregates as >2 mm (Tiemann et al., 2015; Sarker et al., 2018). The stability of wetted soil aggregates indicates the ability of soil to resist water erosion (i.e., water-stable aggregates, WSA), and the size distribution of dry soil aggregates reflects the potential for wind erosion risk. SMAF currently includes indicator scoring for wetted aggregates only (i.e., AGG), though both WSA and dry aggregate size distribution were measured in this project.

The AGG scores were lower under BAU-crop than CRP-old, CRP-new, and BAU-pasture, but this was only significant at higher slope sites ($p = 0.02$, Figure 5). This could possibly be because soils from higher slope positions also had lower SOC and clay (Table 1), which can lead to reduced WSA (Johnson et al., 2009). Low WSA means the soil would be less resistant to erosion since small aggregate are easier to displace than larger aggregates. Greater erosion risk on higher sloping soils is consistent with other studies that show higher soil erosion rates on higher slopes, especially on bare and arable lands (Cerdan et al., 2010; Nunes et al., 2020). Planting perennial grasses on slopes can decrease soil erosion and surface runoff (Chen et al., 2018; Yue et al., 2020).

Soil dry aggregate distribution

The stability of dry aggregates depends on the strength of biologically based bonding agents within aggregates which confers resistance to physical breakdown (Skidmore and Powers, 1982). Agricultural management, such as tillage and stover harvest, typically destroys larger soil aggregates and increases smaller aggregate abundance (Johnson et al., 2016; Ojekanmi and Johnson, 2020), thereby increasing wind and water erosion risks because smaller particles are more easily transported off-site.

Dry aggregate distribution data from the 18 sampling sites are summarized in Figure 6. It shows that decreased land use intensity increased the proportion of larger aggregates, while intense land use resulted in more small aggregates. The CRP-old and BAU-pasture had larger amounts of 3- to 9-mm aggregates than BAU-crop, while CRP-old had smaller amounts of 1- to 2-mm aggregates than BAU-crop. This reflects the fracturing of larger aggregates into smaller units during agricultural operations such as tillage, planting, cultivation, and harvest. Our results suggest that conversion of cropland to CRP, especially for higher sloping sites, can improve soil aggregation, decrease runoff and erosion, and thus improve soil physical health.

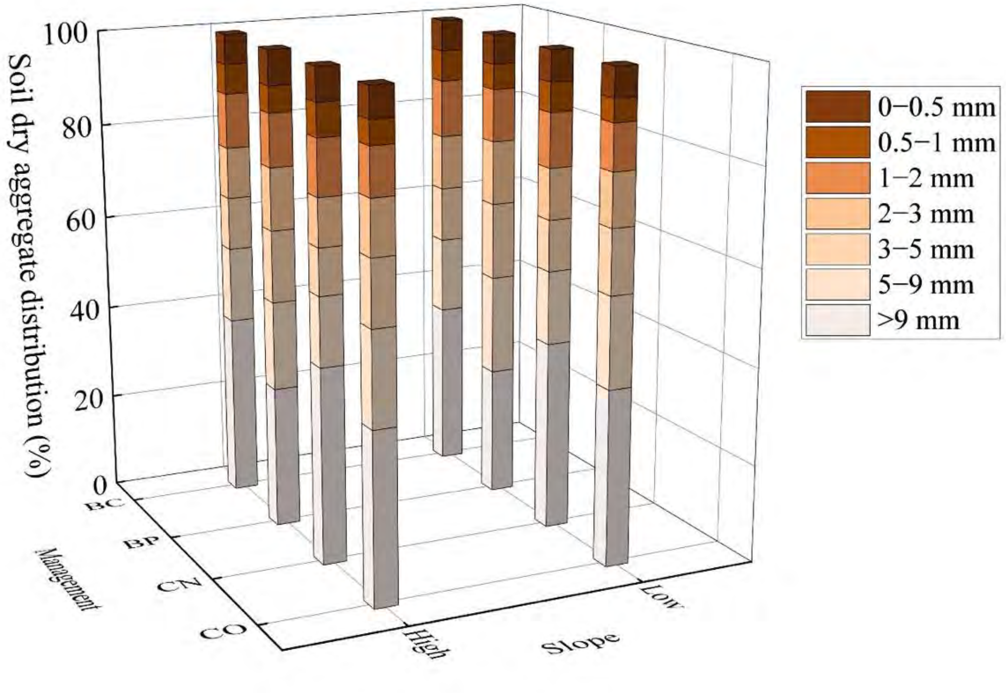

Figure 6. Soil dry aggregate distribution under different management and slopes. BC: business as usual-crop; BP: business as usual-pasture; CO: conservation reserve program-old; CN: conservation reserve program-new.

Structured response model

To further examine baseline soil health indicator response to the four management scenarios beyond SMAF, structural equation modeling was used to quantify effects of (1) land use intensity and (2) CRP enrollment period on soil health indicator scores (Figure 7). The model shows that lower land use intensity and longer CRP enrollment period can improve soil health. Longer enrollment period in CRP directly increased BD scores (effect size = 0.28, $p < 0.001$) but decreased P scores (effect size = −0.40, $p < 0.001$). These changes reflect reduced soil compaction, enhanced below-ground biomass, and the absence of P fertilizer conventionally applied to crops prior to being converted to CRP.

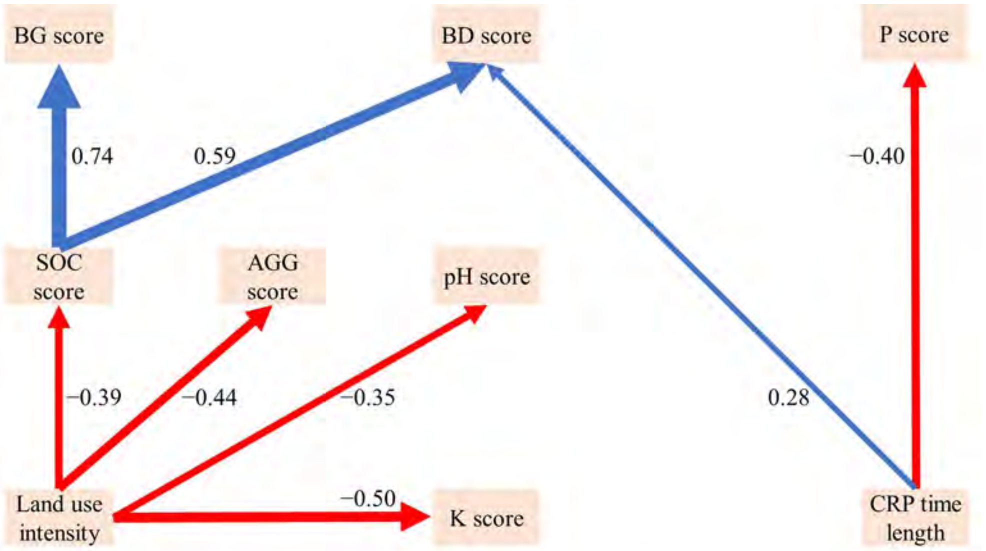

Figure 7. A conceptual structural equation model developed to examine effects of (1) land use intensity and (2) length of a site was enrolled in a CRP program.

> **Model Components**: Land use intensity levels: conservation reserve program (CRP), pasture, and crop; length of time site was enrolled in a CRP program: business as usual (BAU), CRP-new (CN), and CRP-old (CO).
>
> **Indicators**: AGG: water-stable aggregate; BD: bulk density; EC: electrical conductivity; SOC: soil organic carbon; BG: β-glucosidase activity; P: phosphorus; K: potassium.
>
> **Interpretation**: Boxes indicate variables while arrows represent causal relationships at a $p < 0.05$ level. Arrow direction indicates source or response driver; width indicates magnitude of response; color: blue – positive response and red – negative response. Numbers presented beside each arrow are standardized path coefficients (i.e., effect sizes) with goodness-of-fit indices indicating optimal model fit: CMIN/DF = 1.16, GFI = 0.92, CFI = 0.98, RMSEA = 0.046

Decreasing land use intensity (especially the frequency or intensity of tillage operations) will generally improve AGG and SOC scores (effect size = −0.44 and −0.39, respectively, $p < 0.001$) because rather than oxidizing annual C inputs, they are protected due to reduced disruption of soil aggregates and overall soil structure. Enhanced SOC scores are frequently associated with improved BD and BG scores because both are positively influenced by increasing SOC content. Decreased land use intensity can also increase pH and plant-available K scores (effect size = −0.35 and −0.50, $p = 0.001$ and $p < 0.001$, respectively). This occurs because annual synthetic N fertilizer applications gradually acidify soils over time (Liebig et al. 2006; Reeves and Liebig 2016), therefore decreasing the frequency and amount of N fertilizer input will generally reduce the rate of decline in soil pH. Increased SOC concentrations also generally increase cation exchange capacity (CEC), which can increase K adsorption (Ramos et al., 2018; Almeida et al., 2020) and soil-test K levels (i.e., scores). Near-surface soil K scores with decreased land use intensity such as CRP may also increase plant roots translocate subsurface K into the foliage which is then recycled near the soil surface rather than being transported off site by grazing animals, hay, or biomass harvest. Those pathways help describe the overall soil health effects (Table 3) which show that increasing land use intensity decreased AGG, BD, pH, SOC, BG, and K scores.

Table 3 Standardized total effects of land use intensity and CRP time length on soil health scores

	Land use intensity	CRP time length
AGG score	−0.44	0.00
BD score	−0.23	0.28
pH score	−0.35	0.00
EC score	0.00	0.00
SOC score	−0.39	0.00
BG score	−0.29	0.00
P score	0.00	−0.40
K score	−0.50	0.00

The CRP conversion responses on high slope and low slope were evaluated to compare environmental sensitivity of these areas. The structural equation model was applied on high and low slopes respectively. The effect sizes of land use intensity at high and low slope positions were compared in Table 4. Land use intensity had larger effects at high slope than low slope on AGG, pH, and BG scores, indicating conversion to CRP might have stronger benefits to environmentally sensitive soils.

Generally, physical, chemical, and nutrient SQI were consistent with results from other Midwestern studies (0.67 ± 0.04 to 0.98 ± 0.01), but the biological SQI value was rather low (0.19 ± 0.03 to 0.35 ± 0.03). The biological SQI (i.e., SOC and BG scores) might be underestimated by the SMAF scoring curves: however, it was sensitive to land use intensity. Our structural equation (Figure 7) suggests that decreasing land use intensity can directly increase SOC score and further increase BG and BD scores. Hence, conversion of cropland to CRP or other cellulosic feedstock production systems will very likely result in beneficial soil health effects at these sites.

Table 4 Standardized total effects of land use intensity and CRP time length on soil health scores at higher and lower slope positions[†].

	Land use intensity		CRP time length	
	High slope	Low slope	High slope	Low slope
AGG score	−0.67	0.00	0.00	0.00
BD score	−0.21	−0.26	0.29	0.27
pH score	−0.42	−0.29	0.00	0.00
EC score	0.00	0.00	0.00	0.00
SOC score	−0.35	−0.44	0.00	0.00
BG score	−0.29	−0.25	0.00	0.00
P score	0.00	0.00	−0.34	−0.47
K score	−0.48	−0.51	0.00	0.00

[†] Land use intensity levels: conservation reserve program (CRP), pasture, and crop; CRP time length levels: business as usual, CRP-new, and CRP-old; Slope levels: higher slope (13 to 25%) and lower slope (7 to 13%). AGG: water-stable aggregate; BD: bulk density; EC: electrical conductivity; SOC: soil organic carbon; BG: β-glucosidase activity; P: phosphorus; K: potassium.

On-farm catchment study results

In addition to the land use conversion evaluations, ARS scientists also evaluated soil health indicator responses within two on-farm experimental catchments in the South Fork of the Iowa River basin (Figure 8). This site provided data for quantifying the impact of cover crop use to ameliorate corn stover harvest in a no-till continuous corn system fertilized with animal manure.

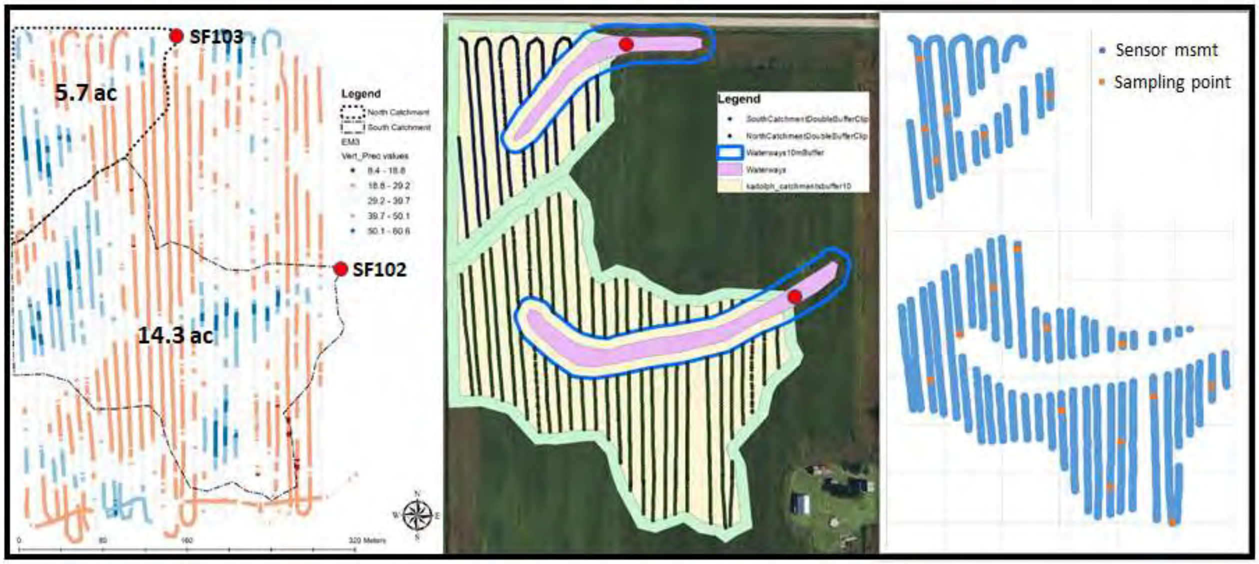

Figure 8. Field-scale paired watershed experiment (Hubbard, IA) showing catchment areas and locations of monitoring flumes (SF102, SF103). Left: Apparent electrical conductivity survey; Center: Survey points retained for developing soil sampling design; Right: Final directed soil sampling design based on statistical analyses of spatial variability (ESAP-RSSD, v. 2.35).

The South Catchment (14.3 acres) was established in 2001 (Tomer et al., 2016) and the North Catchment (5.7 acres) was established in 2017. Soils were surveyed for apparent electrical conductivity using electromagnetic induction (EMI) in October 2017. The EMI survey was used to generate a statistically directed soil sampling design equivalent to a 1-acre grid density to capture the range of spatial variability in each catchment. Soils were sampled in November 2017.

At that site, differences among soil health scores for samples collected from the north and south catchments were mostly not significant (Table 5). This was not unexpected since planting of cover crops in the south catchment was a new management operation. Among individual indicators, BG scores were very low (0.05 ± 0.009); BD and SOC scores were moderate (0.39 ± 0.08 to 0.47 ± 0.13); and AGG, pH, EC, P, and K scores were good (0.84 ± 0.07 to 1.00 ± 0.00).

Table 5. SMAF scores for the on-farm catchment study[†].

Catchment	North catchment	South catchment
Overall SQI	0.74 ± 0.03 (a)	0.70 ± 0.02 (a)
Physical SQI	0.73 ± 0.03 (a)	0.70 ± 0.04 (a)
Chemical SQI	0.99 ± 0.01 (a)	0.97 ± 0.01 (a)
Biological SQI	0.28 ± 0.08 (a)	0.24 ± 0.04 (a)
Nutrient SQI	0.97 ± 0.02 (a)	0.90 ± 0.04 (a)
AGG score	1.00 ± 0.00 (a)	0.96 ± 0.02 (b)
BD score	0.46 ± 0.06 (a)	0.45 ± 0.06 (a)
pH score	0.97 ± 0.01 (a)	0.94 ± 0.02 (a)
EC score	1.00 ± 0.00 (a)	1.00 ± 0.00 (a)
SOC score	0.47 ± 0.13 (a)	0.39 ± 0.08 (a)
BG Score	0.050 ± 0.009 (a)	0.053 ± 0.007 (a)
P score	0.96 ± 0.03 (a)	0.84 ± 0.07 (a)
K score	0.98 ± 0.02 (a)	0.97 ± 0.01 (a)

[†] The overall soil quality index (SQI) includes eight potential soil health indicators: water-stable aggregates (AGG), bulk density (BD), pH, electrical conductivity (EC), soil organic carbon (SOC), β-glucosidase activity (BG), phosphorus (P), and potassium (K). Physical SQI was reflected by AGG and BD, chemical SQI by pH and EC, biological SQI by SOC and BG, and nutrient SQI by P and K. Results are reported as mean values ± standard error. Different letters indicate significant differences between catchments ($p < 0.001$).

KEY SHORT-TERM CONCLUSIONS

- Land use affected soil physical, chemical, biological, and nutrient quality indicators.
- Longer CRP enrollment improved soil physical, chemical, and nutrient quality indicators.
- Soil health status varied most between BAU-crop and CRP-old sites, but few differences were noted between BAU-pasture and CRP sites.
- Decreasing land use intensity increased SOC.

- Converting cropland to CRP increased soil aggregation (i.e., greater macro/mega- aggregates).
- Land use intensity had larger effects at higher slope than lower slope on AGG, pH, and BG scores.

REFERENCES

Almeida, T.F., Carvalho, J.K., Reid, E., Martins, A.P., Bissani, C.A., Bortoluzzi, E.C., Brunetto, G., Anghinoni, I., de Faccio Carvalho, P.C., Tiecher, T., 2020. Forms and balance of soil potassium from a long-term integrated crop-livestock system in a subtropical Oxisol. Soil and Tillage Research, 104864.

Andrews, S. S., D. L. Karlen, and C. A. Cambardella., 2004. The soil management assessment framework: a quantitative soil quality evaluation method. Soil Science Society America Journal. 68:1945-1962.

Cerdan, O., Govers, G., Le Bissonnais, Y., Van Oost, K., Poesen, J., Saby, N., Gobin, A., Vacca, A., Quinton, J., Auerswald, K., 2010. Rates and spatial variations of soil erosion in Europe: a study based on erosion plot data. Geomorphology 122, 167-177.

Chen, H., Zhang, X., Abla, M., Lü, D., Yan, R., Ren, Q., Ren, Z., Yang, Y., Zhao, W., Lin, P., 2018. Effects of vegetation and rainfall types on surface runoff and soil erosion on steep slopes on the Loess Plateau, China. Catena 170, 141-149.

Golchin, A., Oades, J.M., Skjemstad, J.O., Clarke, P., 1994. Soil structure and carbon cycling. Aust. J. Soil Res. 32, 1043–1068.

Johnson, J.M., Papiernik, S.K., Mikha, M.M., Spokas, K., Tomer, M.D., Weyers, S.L., Lal, R., Stewart, B., 2009. Soil processes and residue harvest management. Carbon management, fuels, and soil quality. Taylor and Francis, LLC, New York, 1-44.

Johnson, J.M., Strock, J.S., Tallaksen, J.E., Reese, M., 2016. Corn stover harvest changes soil hydrology and soil aggregation. Soil and Tillage Research 161, 106-115.

Liebig, M., Gross, J., Kronberg, S., Hanson, J., Frank, A., Phillips, R., 2006. Soil response to long-term grazing in the northern Great Plains of North America. Agriculture, Ecosystems & Environment 115, 270-276.

Nunes, M.R., Karlen, D.L., Veum, K.S., Moorman, T.B., 2020. A SMAF assessment of US tillage and crop management strategies. Environmental and Sustainability Indicators 8, 100072.

Nunes, M.R., Karlen, D.L., Moorman, T.B., 2020. Tillage intensity effects on soil structure indicators—A US meta-analysis. Sustainability 12, 2071.

Ojekanmi, A., Johnson, J.M., 2020. Quantifying improvements in water stable aggregation due to corn stover retention. Soil Science Society of America Journal, n/a(n/a). doi:https://doi.org/10.1002/saj2.20198.

Ramos, F.T., Dores, E.F.d.C., Weber, O.L.d.S., Beber, D.C., Campelo Jr, J.H., Maia, J.C.d.S., 2018. Soil organic matter doubles the cation exchange capacity of tropical soil under no-till farming in Brazil. Journal of the Science of Food and Agriculture 98, 3595-3602.

Reeves, J.L., Liebig, M.A., 2016. Depth matters: soil pH and dilution effects in the northern Great Plains. Soil Science Society of America Journal 80, 1424-1427.

Sarker, J.R., Singh, B.P., Cowie, A.L., Fang, Y., Collins, D., Badgery, W., Dalal, R.C., 2018. Agricultural management practices impacted carbon and nutrient concentrations in soil aggregates, with minimal influence on aggregate stability and total carbon and nutrient stocks in contrasting soils. Soil Till. Res. 178, 209-223.

Six, J., Elliott, E.T., Paustian, K., 2000. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. Soil Biol. Biochem. 32, 2099–2103.

Skidmore, E.L., and D.H. Powers., 1982. Dry soil-aggregate stability: Energy-based index. Soil Sci. Soc. Am. J. 46:1274–1279.

Tiemann, L.K., Grandy, A.S., Atkinson, E.E., Marin-Spiotta, E., McDaniel, M.D., 2015. Crop rotational diversity enhances belowground communities and functions in an agroecosystem. Ecology Lett. 18, 761-771.

Tisdall, J.M., Oades, J.M., 1982. Organic-matter and water-stable aggregates in soils. J. Soil Sci. 33, 141–163.

Tomer, M.D., T.B. Moorman, J.L. Kovar, K.J. Cole, and D.J. Nichols., 2016. Eleven years of runoff and phosphorus losses from two fields with and without manure application, Iowa, USA. Agricultural Water Management. 168:104-111.

Wienhold, B. J., D. L. Karlen, S. S. Andrews, and D. E. Stott. 2009. Protocol for indicator scoring in the Soil Management Assessment Framework (SMAF). Renewable Agriculture Food Systems. 24(4):260-266.

Yue, L., Juying, J., Bingzhe, T., Binting, C., Hang, L., 2020. Response of runoff and soil erosion to erosive rainstorm events and vegetation restoration on abandoned slope farmland in the Loess Plateau region, China. Journal of Hydrology 584, 124694.

No. 11. Saturated Riparian Buffers: A Landscape Conservation Practice Linking Water Quality and Biomass Sources

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Sustainable landscape designs provide multiple ecosystem services including provision of biomass feedstock, water resource protection, optimum crop production, and reduced negative environmental impact. Saturated Riparian Buffers (SRB) are potential, relatively new conservation practice that can improve water quality and provide a sustainable supply of biomass. On-going research and technology transfer projects led by the USDA-Agricultural Research Service (ARS) with USDA Natural Resources Conservation Service (NRCS) and several state, local, and private sector partners were leveraged to complement landscape design research associated with the "Enabling Sustainable Landscape Design for Continual Improvement of Operating Bioenergy Supply Systems" project. This case study provides an overview of those activities which were brought together by this project within the South Fork of the Iowa River watershed, located within the Nevada, IA biomass supply-shed.

What is a Saturated Riparian Buffer? Vegetated riparian buffers can help improve water quality in agricultural watersheds. However, artificial (tile) drainage dominates the hydrology of many Midwestern watersheds where poorly drained soils are common, and tile drainage water bypasses riparian-zone soils via drainage pipes. This drainage water carries substantial loads of nitrate that impact the size of the hypoxic zone in the northern Gulf of Mexico each year. The saturated riparian buffer (SRB) diverts tile drainage water to riparian soils, using water level control gates and distribution lines placed at shallow depth in riparian soils. Field studies have shown the SRB practice can be highly effective in removing nitrate from drainage water, especially in riparian zones where saturated conditions and available soil carbon combine to encourage microbial denitrification. Denitrification is a process that converts aqueous nitrate (NO_3-N) into di-nitrogen gas, which is harmless, to the atmosphere.

Where can Saturated Riparian Buffers be placed? The capacity for a SRB practice to impact nitrate losses at watershed scale depends on the extent of riparian sites that are suitable for SRB installation. The extent of SRB-suited sites in Iowa has been estimated using a GIS-based conservation planning tool called the Agricultural Conservation Planning Framework (ACPF; see www.acpf4watersheds.org). The ACPF toolbox includes an SRB-siting tool that identifies riparian zones where soil carbon levels and shallow water tables can facilitate denitrification, and where installation of the SRB practice presents minimal risks for inundation of adjacent croplands and/or sloughing of stream banks. This SRB tool has been applied throughout Iowa and results are available on-line (https://benson.gis.iastate.edu/acpf/satbuff.html). Approximately 17,000 miles of Iowa stream banks are suited to SRB placement (note: there are two miles of stream bank per mile of stream length). A detailed analysis of a subset of small (i.e., HUC-12; 10,000-40,000 acres) headwater watersheds in eastern and central Iowa, showed that SRBs could be placed on 30 to 70% of streambanks and reduce NO_3-N loss in tile drainage from 15 to 40% of the watershed areas. These estimates consider the likely extent of tile drained lands by watershed, but overall, indicate that SRB installation is an important new conservation option that can impact nitrate losses in many Midwestern watersheds.

Considerations for use of Saturated Riparian Buffers for biomass production. Saturated riparian buffers will often be placed within Conservation Reserve Program (CRP) buffers that, by current USDA rule, cannot be harvested. However, biomass production would be feasible at many SRB-suited riparian sites that are not enrolled in the CRP program, and many producers may want to consider using these new conservation efforts to potentially increase farm income. The SRB practice raises the water table to increase soil water availability, which can enhance growth of perennial crops. Harvesting biomass also provides a nutrient-removal sink that could improve an SRB's overall environmental performance, while providing additional farm income upon sale of harvested material. Assuming a relatively narrow buffer width of 50 ft and 17,000 miles of sites potentially suited to the SRB practice, there could be 103,000 acres of riparian zones in Iowa that could contribute to the land base for biomass production in Iowa, while providing multiple other ecosystem services and conservation benefits. Limited areas of marginal cropland would be removed from production under this scenario for improving water quality through a landscape approach to conservation.

On-going SRB research and this Landscape Design Project were leveraged to complement both efforts within the South Fork of the Iowa River Watershed, located in the Nevada, IA biomass supply-shed. Key activities included an on-farm field day that allowed farmers to observe the installation of an SRB, demonstrated on-site by commercial drainage installation contractors. More than 50 farmers attended this event, which was hosted by the Southfork Watershed Alliance (SFWA), a local, farmer-led watershed advocacy group (see www.southforkwatershed.org). The SFWA has also hosted workshops that enabled producers to review ACPF results suggesting conservation practice options on their farms. Workshops were held at a computer lab of the local community college (Ellsworth CC). A state-awarded watershed planning grant is being used to promote new conservation practices and recruit producers to apply for cost share programs that assist with practice installation. This watershed is extensively tile drained and has riparian conditions conducive to SRB installation along multiple stream reaches. Producers have been specifically encouraged to install SRBs as part of this project, although this outreach was tabled by the Covid-19 pandemic. The website that displays ACPF results for the South Fork watershed is accessible at http://arcg.is/1qKn80.

Additional reading:

Lewandowski, A.M., M.D. Tomer, J. Buchanan, A. Kiel, J.J. Sloan, L. Olson, and R. Power. 2020. Agricultural Conservation Planning Framework: Watershed applications, research opportunities, and training resources. Journal of Soil & Water Conservation. 75(4):427-433.

Tomer, M.D., S.A. Porter, D.E. James, and J.D. Van Horn. 2020. Potential for saturated riparian buffers to treat tile drainage among 32 watersheds representing Iowa landscapes. Journal of Soil & Water Conservation. 75(4):453-459.

No. 12. Biomass Market Access Strategy (BMAS) Development and Implementation Plan

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A critical requirement for acceptance and implementation of any landscape design is market access for the products produced from those endeavors. Current markets are dismal because of low global oil and gas prices, but those are finite resources and someday the results of this landscape design study will be called upon to rekindle essential, sustainable cellulosic feedstock production, harvest, transport, and storage. One of many activities leveraged by this landscape design project has been continued development of the Biomass Market Access Standards (BMAS), a certification system and corresponding verification process for the sustainable production of biomass for bioenergy in the United States. This system is based on a voluntary sustainability standard for biomass growers that was developed in 2012 by the Council on Sustainable Biomass Production (CSBP). The CSPB Standard was developed on a consensus-basis by a large group of stakeholders to help promote sustainability as part of the basis on which the cellulosic biofuels industry is built, and to set this emerging industry on a course of continuous improvement.[2]

The BMAS tool and certification system was conceived and developed as a result of lessons learned during field-testing of the CSBP Standard. In particular, the amount of effort required to respond to each of the questions in the interview process and to develop supporting documents was found to be a significant adoption barrier. The primary purpose for the BMAS site is to: (i) gather information from the applicant, including supporting documentation as applicable to support responses to questions, (ii) have that information available to a certification body, and (iii) minimize the amount of support needed from an external third party to complete the certification process.

Constructed as a web-based platform[3], BMAS is intended to optimize and streamline both the application and verification processes. The system provides a scalable and traceable method to obtain information and documentation from applicants. The platform also includes guidance and support to clarify questions and input needs, streamline checklist completion, and automatically generate an integrated resource management plan (IRMP) during the input review phase.

Other BMAS aspects that are still under development include linkages to external modeling tools, consumer-developed sustainability planning information, USDA information sources, and other credible resources that can be used to automatically populate entries or provide template information as a starting place. As part of the certification process, BMAS can also serve as an interface with the certification body (auditor) and provide a platform for the individual to approve or deny applications for certification.

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[2] Funding for the CSBP process was provided as part of a USDA Conservation Innovation Grant.
[3] The BMAS platform can be accessed through this website, https://bmascertified.org/

Description of the BMAS Platform

Figure 1 outlines the aspects of the BMAS application and certification process. The application is divided into four main sections: (1) Farm and Fields; (2) Introduction; (3) Questionnaire; and (4) Review. The portal also provides an option to connect with an auditor for full certification.

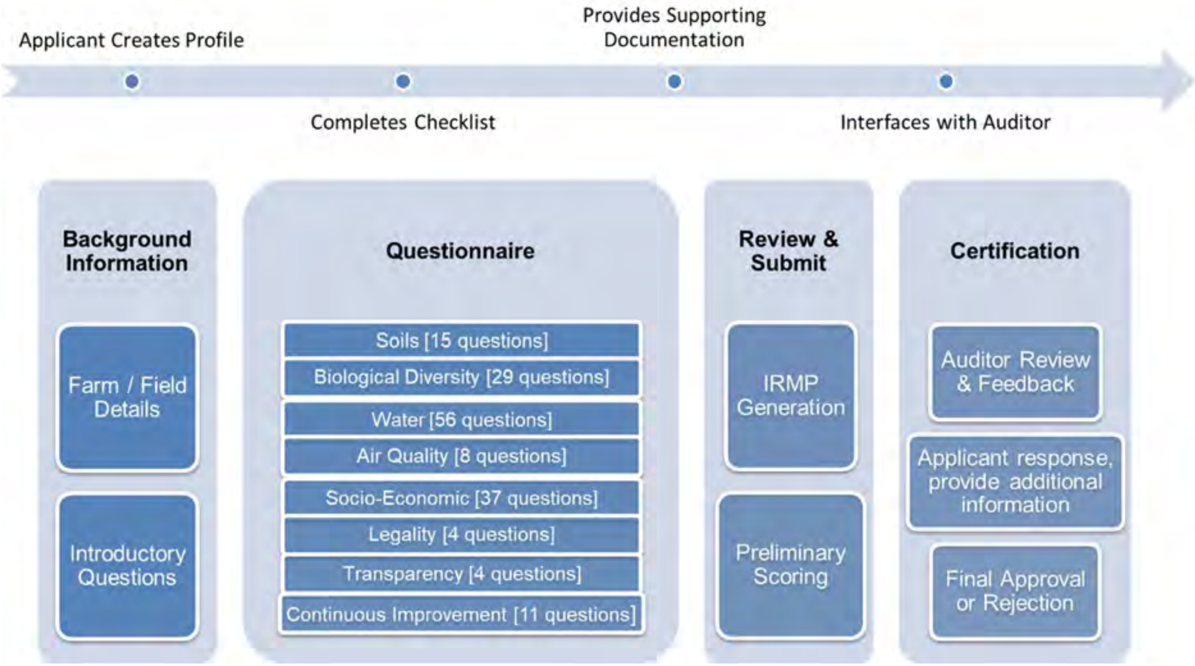


Figure 1. An overview of the process and components of the BMAS webtool

The ***Farm and Fields*** section is where the applicant inputs information about farming practices, which is base information for sustainability considerations. It includes geographic coordinates defining where the fields are located, and information regarding cropping history, yields, soil type, irrigation, fertilization and other inputs, tillage frequency and intensity, and equipment used. There are also inputs for post-harvest operations such as product drying and hauling.

The ***Introduction*** section includes a limited number of broad questions that are used by the tool to pre-fill questions in the Questionnaire section of the tool. This feature saves the user time by pre-selecting answers to questions so that the user can skip over questions that are not relevant to their specific field(s) or operation. For example, if the applicant responds that fields are not irrigated in the Introduction section, later questions on irrigation in the Water portion of the questionnaire will be automatically indicated to be not applicable.

The ***Questionnaire*** section delves into the certification principles and uses the same organization and language as the Standard it is based upon. There are 164 questions, although some may not be applicable depending on applicant-specific responses. Almost all of the questions use a “Yes, No, Not Applicable” response, with commentary and document upload options for supporting documents when applicable. The IRMP questions are the only ones requiring a written response, as this text is also used to prepare a complete IRMP document for the applicant. All questions have a help button which provides the user with context-specific clarification and/or supporting information. This includes examples of compliant activities and guidance on where to get supporting documents from public sources such as the USDA/NRCS.

Examples of the built-in benefits for completing the questionnaire include:

- Interconnectivity to streamline application by avoiding questions that are irrelevant
- Answers and other inputs are automatically saved
- A status bar for each section gives the user an indication of how close they are to completing the section.
- The applicant can skip questions and come back later. Any skipped questions are indicated in the questionnaire scorecard summary view.

The ***Application Review*** section provides a summary of all collected information for review by the applicant. There is a Table of Contents with links at the top, as well as a floating navigation bar. This section also serves as an exportable IRMP report - each section from the Questionnaire is listed with all the answers that helped the applicant achieve points towards certification. The answered questions include any comments made by the applicant. At the end of the page the Appendices section shows all attached supporting documentation, organized by section.

The applicant also receives a preliminary Score Summary chart, showing what sections they did and did not pass, as well as the threshold value needed for certification. If the applicant did not pass, the Summary indicates the critical issues. If the applicant passed, the application can be submitted to a user-selected certifier to complete the certification review process.

Certification: The certifier portal allows a certifier to review an application and provide feedback to the applicant. From the portal, the certifier can view read-only versions of all inputs in the Farm and Fields and Questionnaire sections, including all attachments. There is also a Review page that shows the automatically-generated IRMP from the application, which includes the IRMP questions and responses and all correctly-answered questions and their responses and attachments. The certifier can provide comments for each question, and mark them with the following options: Compliance, Non-Compliance, Partial Compliance, New Info Request, or N/A. These options are used to communicate any identified issues or missing data with the applicant. Following the initial review, the application may be returned to the applicant, and they will be able to see certifier responses and have the opportunity to provide additional information or documentation that can change the final score. The scores are based on the number of questions that have achieved compliance or partial compliance with the standard relative to the total number of relevant questions for the applicant on a category level.

Administration: The BMAS webtool includes an Administration Dashboard, that allows administrators to make modifications to various sections of the tool. This includes customizing farm and field drop-downs and changing or adding questions in the Introduction and Questionnaire sections, such as dependencies and/or setting scoring thresholds for passing. The flexibility afforded from this section is important for keeping the content fresh and allowing ongoing improvements as the requirements change. Ultimately, we envision BMAS being supported by a Technical Advisory Board that will direct any changes to the requirements.

Summary of Efforts to Date

All BMAS platform activities to date have been done as part of the Landscape Design project. This includes:

- Development of a website that gives an introduction to BMAS and a link to the platform
- Development of an interactive web-based platform with:
    - An input section to characterize management practices at farm and field levels
    - A grower questionnaire for inputs based on CSBP Sustainability Standard
    - Preliminary Scoring and IRMP generation
    - Administrative functionality
    - Certification functionality
- Internal testing and validation
- Completion of two real-world applications with all required supporting documentation, as well as testing third party certification process with an auditor

Case Study Results:

The BMAS testing effort included preparing two complete applications based on actual existing farm operations, each of which included inputting a full set of application responses and supporting documentation into the portal. The case studies also included completing the certification process with an external certifier, who used the certification portal for application review and providing feedback to applicants. Ultimately, both applications submitted and reviewed for the case study effort met the requirements for certification by obtaining scores in each section that were above the minimum threshold. The certifier prepared a summary report for each applicant documenting the review process and final outcome.

This effort provided a lot of insight into the process for both the applicant and the certifier, and lead to many completed and planned improvements for functionality of the portal. Such testing is crucial to developing a platform that will be widely useful in the long run.

Next Steps

There are several planned activities for continued development of the platform and enhanced functionality. Figure 2 shows the overall vision for the BMAS framework. Efforts to date have centered around development of the platform tool itself since it is the basis for data collection and interactivity between relevant stakeholders. One of the next steps is to develop linkages to external systems and tools that can be used to automatically generate inputs and supporting data for some aspects of the process. This is expected to include connection to tools and models from other Landscape Design team member such as EFC Systems FieldAlytics, which can be used for farm and field inputs and practices, as well as the USDA Agricultural Conservation Planning Framework (ACPF) which can be used to help provide template responses and supporting documentation for soil and water sections. ORNL BioSTAR may also be used for supporting materials related to soil, biodiversity, water, and other impacts.

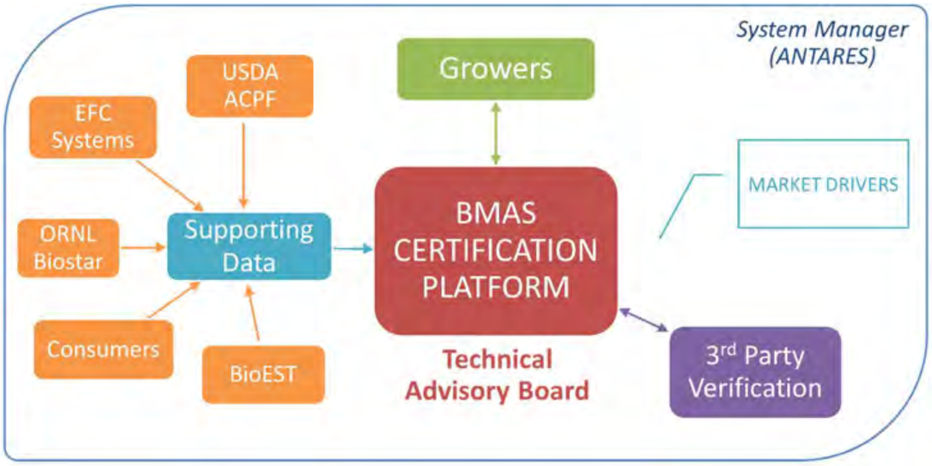


Figure 2. BMAS Interface Framework

Additional field testing will help ensure the BMAS platform is a robust system that can be employed in a wide range of conditions. Further development of the certification process will also be needed, including a certification standard and governing body. A technical advisory board would support these developments, as well as an update to the Standard. Once all of the pieces are in place, demonstration and outreach can be used to inform users of the benefits of BMAS certification.

There is also interest in developing a process to utilize the information already gathered during the input process to calculate the carbon impact (GHG emissions) associated with farm and field management practices. Ultimately, this can be used by growers to see how they compare against benchmark data for typical emissions associated with production of similar crop types and locations.

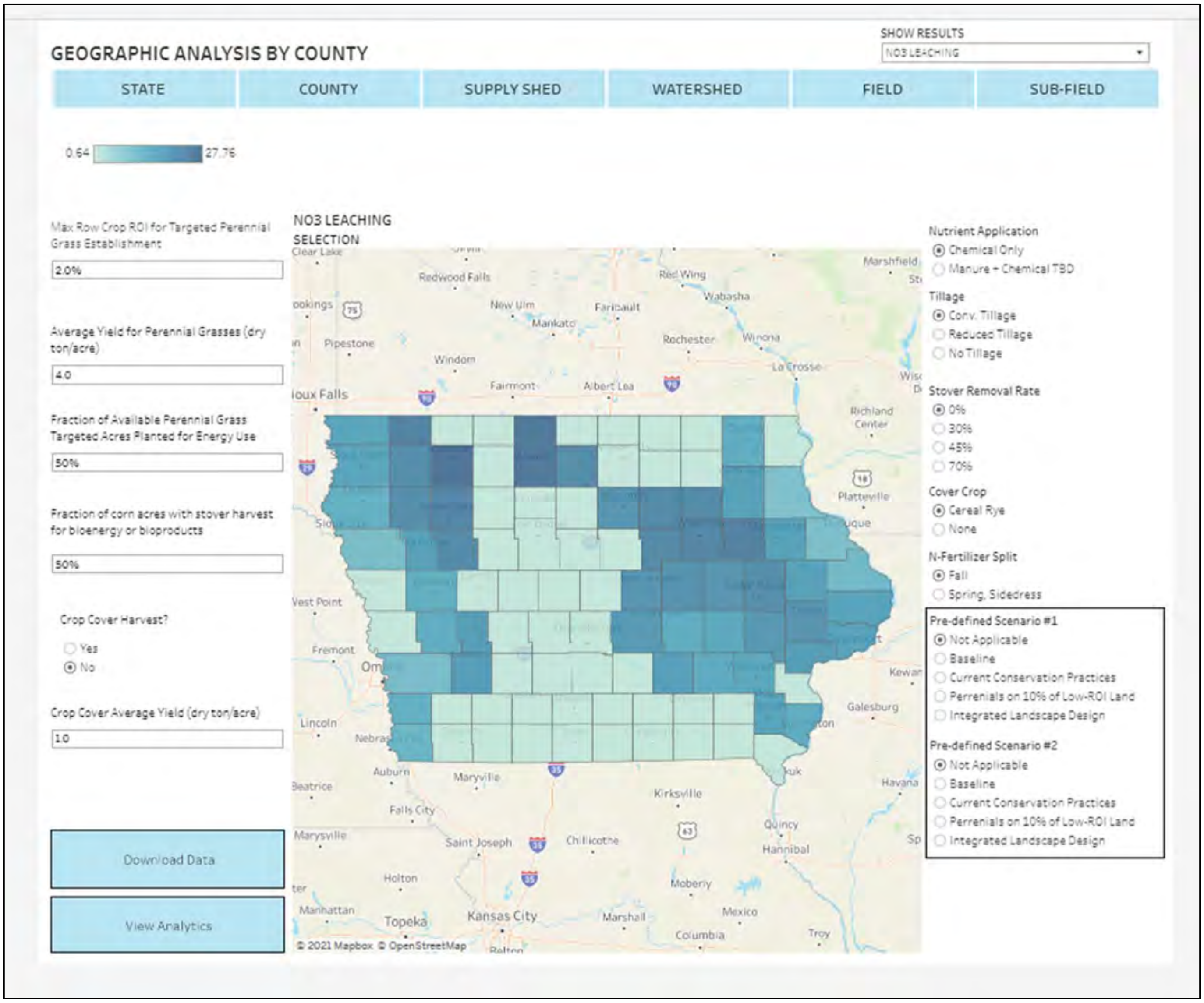
No. 13. An Interactive Tableau™ Interface for Landscape Design Planning

Esther Parish (parishes@ornl.gov)

At the beginning of this project, EFC Systems provided Antares with subfield modeling results for 50 alternative cropping scenarios that were evaluated across the State of Iowa. The tabular data were coupled with ArcGIS shapefiles to create "AgSolver Data" which could be aggregated to provide detailed information about baseline profits and potential environmental effects at county and watershed scales of interest. Collectively, there are environmental results for 48 corn/soybean management scenarios involving combinations of three tillage types (conventional till, reduced till, no till), use of cover crops (winter rye versus none), corn stover harvest at different rates (none, 30%, 45%, or 75%), and fall versus spring fertilizer application.
The dataset also includes environmental modeling results from two scenarios comparing effects of replacing acres planted to corn and soybean during 2013 to 2016 with perennial switchgrass or Conservation Reserve Program (CRP) grasses. A Profit Zone Manager (PZM) file was created to provide return on investment (ROI) data for those years with and without CRP rental payments. This modeling was done to support the Landscape Design project by enabling stakeholders and Team members to examine corn, soybean, switchgrass, and CRP at multiple scales including subfield units. The scaling is accomplished using subfield polygons that reflect intersections between farm boundaries [defined as common land units (CLUs)], counties, 12-digit hydrologic unit codes (HUCs), and SSURGO soil map units (SMU). Collectively this creates over 4 million subfields across the State of Iowa, which makes visualizing the data with any clarity across 50 different cropping scenarios very difficult and rapidly consumes more than 1 terabyte of computer disk storage space.

To make the data more useful and beneficial for decision makers, Antares leadership and other Team members worked with Data Brains™ to develop an interactive user-friendly interface to explore these large and detailed datasets. Since commercial Tableau™ software had previously been selected as the platform for visualizing and evaluating DOE's Billion Ton datasets and had a proven ability to handle large, complex datasets, it was also chosen to help visualize Landscape Design data.

This Case Study highlights a Tableau™ dashboard interface (**Figure 1**) that allows decision makers to examine the AgSolver™ results at different spatial scales. This includes aggregating at state, county, watershed, feedstock supply-shed, and field unit scales for analysis. A drop-down menu at the top of the screen allows users to select an environmental indicator of interest, such as annual soil organic carbon (SOC) change, nitrate (NO_3) leaching, volatized ammonia (NH_3), methane (CH_4) flux, soil conditioning index (SCI), wind erosion, water erosion, or nitrous oxide (NO) emissions. Socioeconomic indicators such as ROI, profit, and biomass production potential can also be selected from the dropdown menu. Radio buttons arranged along each edge of the map allow the user to select from different management practices (e.g., percent corn residue removal). Buttons at the lower left side of the dashboard allow the user to export data tables associated with the desired visualization for use in other applications.



SHOW RESULTS: NO3 LEACHING

Max Row Crop ROI for Targeted Perennial Grass Establishment: 2.0%

Average Yield for Perennial Grasses (dry ton/acre): 4.0

Fraction of Available Perennial Grass Targeted Acres Planted for Energy Use: 50%

Fraction of corn acres with stover harvest for bioenergy or bioproducts: 50%

Crop Cover Harvest?
○ Yes
● No

Crop Cover Average Yield (dry ton/acre): 1.0

Nutrient Application
● Chemical Only
○ Manure + Chemical TBD

Tillage
● Conv. Tillage
○ Reduced Tillage
○ No Tillage

Stover Removal Rate
● 0%
○ 30%
○ 45%
○ 70%

Cover Crop
● Cereal Rye
○ None

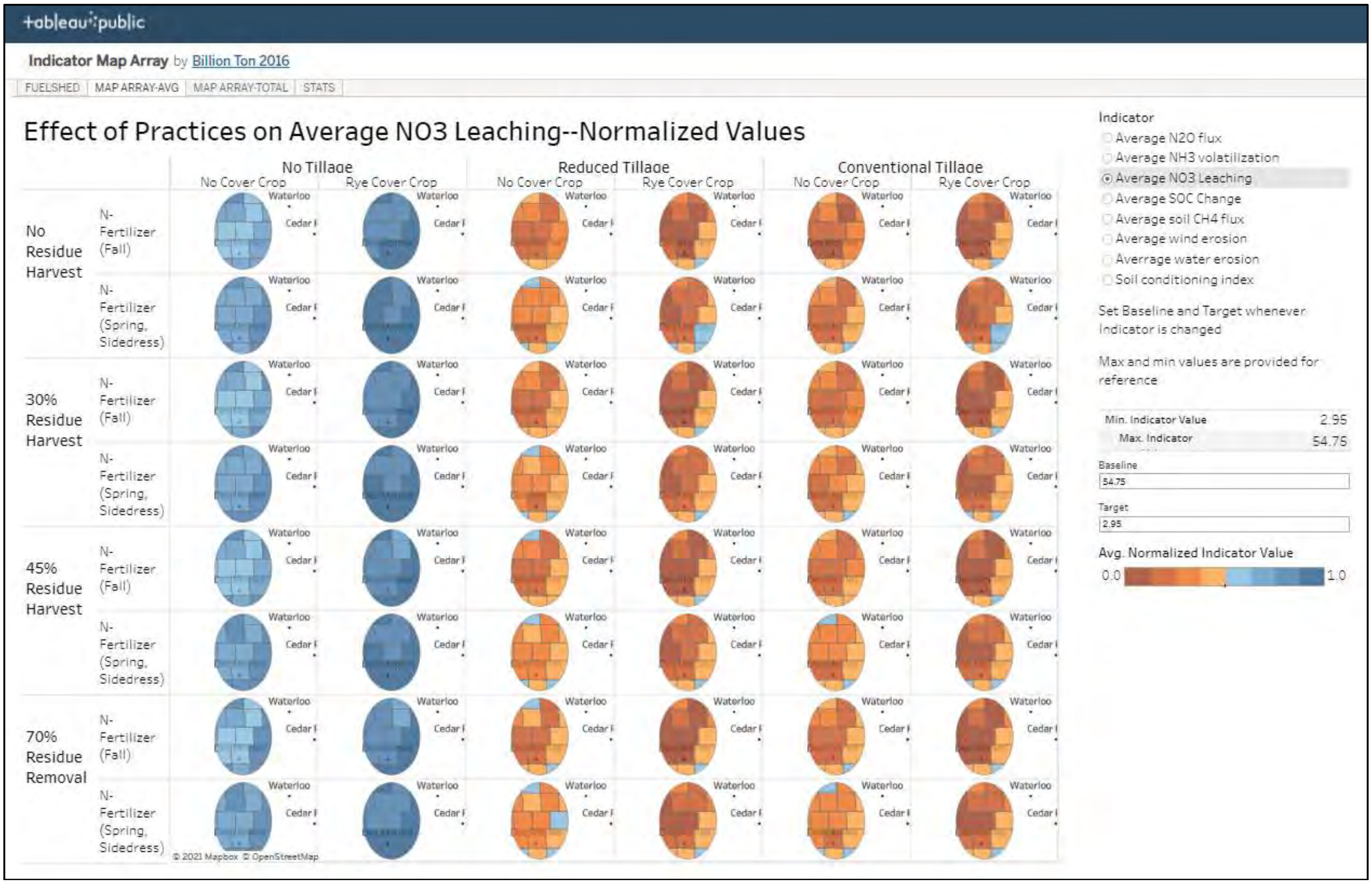
N-Fertilizer Split
● Fall
○ Spring, Sidedress

Pre-defined Scenario #1
● Not Applicable
○ Baseline
○ Current Conservation Practices
○ Perrenials on 10% of Low-ROI Land
○ Integrated Landscape Design

Pre-defined Scenario #2
● Not Applicable
○ Baseline
○ Current Conservation Practices
○ Perrenials on 10% of Low-ROI Land
○ Integrated Landscape Design

Figure 1. Tableau dashboard user interface developed by Kevin Comer (Antares) and Kim Unger (Data Brains).

ORNL researchers built a second Tableau™ interface for the internal team to use for examining potential tradeoffs and synergies among AgSolver's environmental indicators under different management practices (**Figure 2**). The array of 48 small maps is designed to display normalized indicator values for the counties associated with the biomass supply-shed surrounding Nevada, IA. The results are presented in rows and columns that allow users to compare potential costs and benefits associated with different management practices for each environmental indicator (in this case, nitrate leaching in pounds per acre per year). The columns group practices by tillage type and cover crop (i.e., with or without rye cover crop). The rows group the practices by corn residue removal rates and the seasonal time of nitrogen fertilizer application. The normalized maps are colored based on the range of the selected indicator's values (which in this case of nitrate leaching ranges from 2.95 lbs/acre to 54.75 lbs/acre). Thus, this interactive visualization allows each indicator value to be explored using four discrete attributes across 16 counties.



Indicator Map Array by Billion Ton 2016

Effect of Practices on Average NO3 Leaching--Normalized Values

Indicator
○ Average N2O flux
○ Average NH3 volatilization
● Average NO3 Leaching
○ Average SOC Change
○ Average soil CH4 flux
○ Average wind erosion
○ Averrage water erosion
○ Soil conditioning index

Set Baseline and Target whenever Indicator is changed

Max and min values are provided for reference

Min. Indicator Value 2.95
Max. Indicator 54.75
Baseline 54.75
Target 2.95

Figure 2. Map array developed by Mike Hilliard and Esther Parish of ORNL and described in Parish et al. (2021). The small maps are colored based on the range of NO_3-N leaching which ranges from 2.95 to 54.75 pounds/acre across the 16 counties in the Nevada fuelshed. Thus, this interactive visualization thus allows each indicator value to be explored relative to potential management practices.

Reference

Parish, E., Dale, V., Davis, M., Efroymson, R, Hilliard, M., Kline, K., Jager, H., and Xie, F. 2021. An Indicator-based Approach to Sustainable Management of Natural Resources. Chapter 12 in: Jennifer Dunn and Prasanna Balaprakash (eds.) Data Science Applied to Sustainability Analysis. Elsevier. 310 pp

Acknowledgement

This Case Study reflects a collaboration between Antares, EFC Systems, Data Brains, and the ORNL

No. 14. Estimating the Switchgrass Breakeven Price for Enhanced Landscape Design

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Farmers evaluating the merits of incorporating switchgrass into their landscape design will first ask "will this change have a positive, negative, or neutral effect on my bottom-line"? Will they be able to achieve the same return on investment (ROI) producing and selling both switchgrass and their traditional cash crops? If a farmer is able to increase net revenue by implementing a more complex landscape design than simply planting large field areas to one or two annual grain crops, we anticipate they will be incentivized to implement the necessary management changes.

To confirm our hypothesis, it was necessary to know the breakeven price of switchgrass, defined as value to the farmer in dollars per ton ($/ton) of dry matter at which the farmer is indifferent between landscape design methods and traditional row crops. We calculated that price using a comprehensive process summarized in three steps listed below:

1. Estimate the breakeven cost of producing corn as the foundation for our base case. Then add a profit margin and assume that the breakeven cost, plus profit margin ($/bu) equals the corn price. Multiplying that price by the production area, enables us to determine the net revenue (i.e., ROI) associated with producing 100% corn (base case).
2. Determine the net revenue from corn using a landscape design where fewer acres are dedicated to corn production and the less productive acres have been converted to switchgrass.
3. Determine the breakeven price of switchgrass by: (1) calculating the total cost for incorporating switchgrass into the diverted field areas, including increased machinery costs, time costs, and labor costs, and (2) adding the difference in corn revenue between the base- and landscape design-case. This will determine the total switchgrass revenue needed to at least breakeven and thus the minimum switchgrass price needed to provide the farmer with at least the same ROI.

For this analysis, we defined the price of corn as the production cost plus a 15% markup, even though that may not be the value a farmer receives. Our rationale was that we wanted a level playing field between traditional farming operations and more complex landscape design, and that over the long run, commodity prices tend to follow production cost plus a margin. Using the defined price of corn, we calculated the difference in net revenue between business as usual (BAU) and a landscape design optimizing corn production areas and moving other areas into switchgrass. This enabled us to determine the minimum switchgrass price for a breakeven ROI. Calculations were made with and without a fixed land rent for every acre, rather than allocating it according to productivity, which left the total revenue needed for each field unchanged.

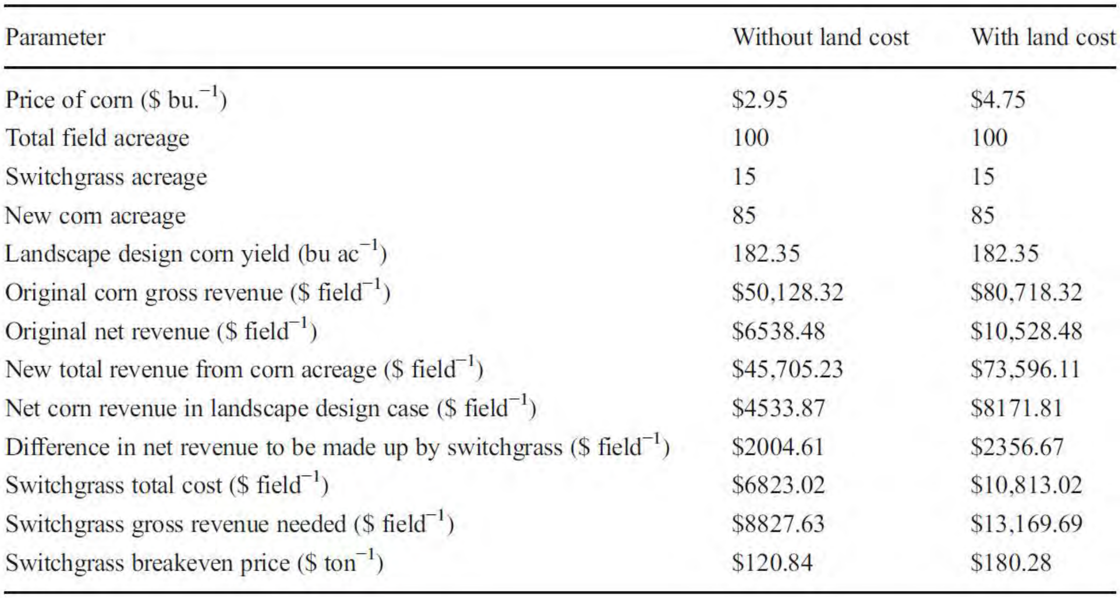
To illustrate this process, we calculated the breakeven price for switchgrass ($/ton) under two scenarios: (1) a general case of a 100-acre field with 15% of the land found to be unprofitable for row crops and therefore converted to switchgrass, and (2) a four-farm analysis of 11 fields with farm level data extracted from AgSolver (Case Study 1).

Cost of production for corn ($/acre) in the base case was determined using the University of Nebraska's 2016 Crop Budgets, Iowa State University's 2016 AgDecision Maker tool, Iowa State University's Corn Drying Cost Calculator, and University of Tennessee's Grain Hauling Cost Calculator. We assumed a 100-acre, no-till, continuous corn cropping system. Two budget categories: (1) Field Operations and (2) Materials & Services were defined with the first including herbicide and fertilizer application, planting, equipment costs (combine, grain cart, and truck), and drying cost per acre. This category also included all labor, repair and fuel costs. The second included all fertilizer, herbicide, and insecticide materials, scouting, crop insurance and miscellaneous costs per acre.

For both cases of farm types, the analysis assumes that planting costs of corn remain the same as there will be no need for additional drive time to avoid the switchgrass stand during the planting phase. However, to harvest the corn in the landscape design case, farmers are assumed to have additional drive time to get around the switchgrass plots to harvest corn, thus increasing machinery and labor costs as the machinery is now less efficient. Additionally, both scenarios were performed with and without a land rent charge of $266 per acre.

In the general case of a 100-acre field with 15 acres converted to switchgrass production, the breakeven price of switchgrass ($/ton) was found to be $180.28/ton or $120.84/ton with or without land charges, respectively. The results from the baseline scenario are summarized in Table 1.

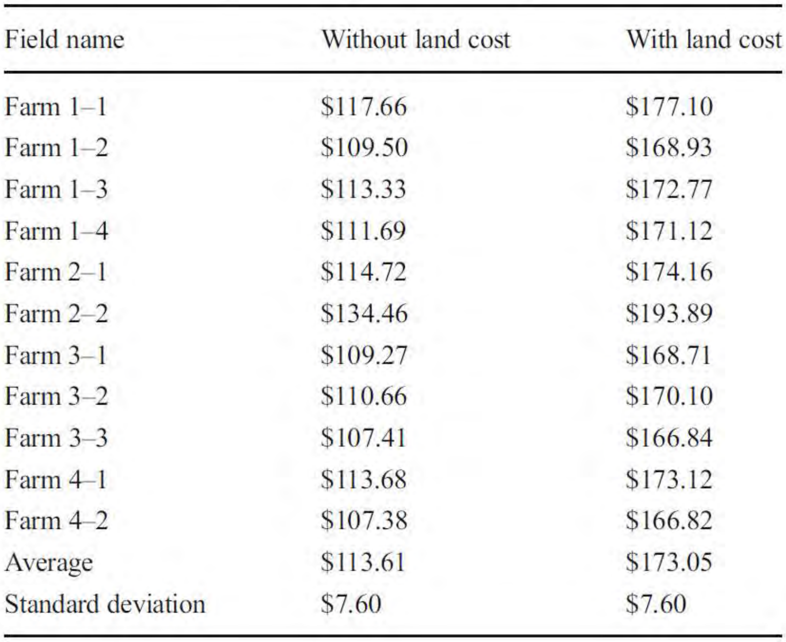
Table 1. Switchgrass breakeven prices for a 100-acre baseline scenario (Soldavini & Tyner, 2017).



Parameter	Without land cost	With land cost
Price of corn ($ bu.$^{-1}$)	$2.95	$4.75
Total field acreage	100	100
Switchgrass acreage	15	15
New corn acreage	85	85
Landscape design corn yield (bu ac^{-1})	182.35	182.35
Original corn gross revenue ($ field^{-1})	$50,128.32	$80,718.32
Original net revenue ($ field^{-1})	$6538.48	$10,528.48
New total revenue from corn acreage ($ field^{-1})	$45,705.23	$73,596.11
Net corn revenue in landscape design case ($ field^{-1})	$4533.87	$8171.81
Difference in net revenue to be made up by switchgrass ($ field^{-1})	$2004.61	$2356.67
Switchgrass total cost ($ field^{-1})	$6823.02	$10,813.02
Switchgrass gross revenue needed ($ field^{-1})	$8827.63	$13,169.69
Switchgrass breakeven price ($ ton^{-1})	$120.84	$180.28

Another evaluation using 11 field studies across four farms resulted in a range of switchgrass breakeven prices ($107.38/ton to $134.46/ton) if there was no land rent cost. When land rent was included, the estimated breakeven price ranged from $166.82 to $193.89 per dry ton. Results for the four-farm case are presented in Table 2. The significant difference with and without land rent case illustrates that this variable will be a key factor influencing a farmer's decision to plant switchgrass on their farm.

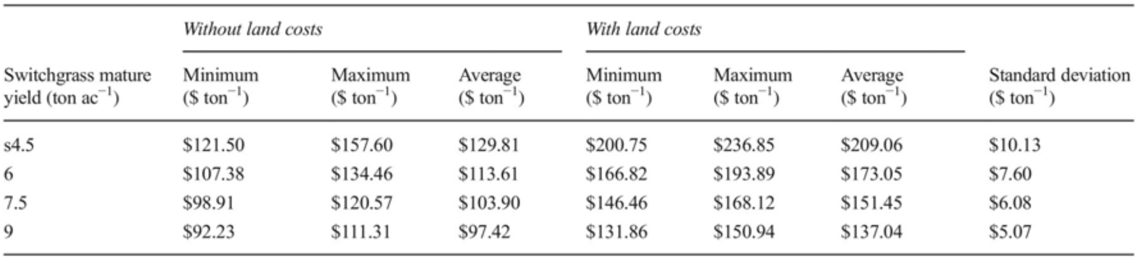
Table 2. Field analyses switchgrass breakeven prices ($/ton) (Soldavini & Tyner, 2017)



Field name	Without land cost	With land cost
Farm 1–1	$117.66	$177.10
Farm 1–2	$109.50	$168.93
Farm 1–3	$113.33	$172.77
Farm 1–4	$111.69	$171.12
Farm 2–1	$114.72	$174.16
Farm 2–2	$134.46	$193.89
Farm 3–1	$109.27	$168.71
Farm 3–2	$110.66	$170.10
Farm 3–3	$107.41	$166.84
Farm 4–1	$113.68	$173.12
Farm 4–2	$107.38	$166.82
Average	$113.61	$173.05
Standard deviation	$7.60	$7.60

As farmers produce switchgrass in real-life settings, their input prices, yields, and other variables will differ from the assumptions used in this analysis. Therefore, we conducted sensitivity analysis on these results. Sensitivity analysis was performed on several assumptions including switchgrass yield, average field size, corn yield, and the fraction of the field allocated to switchgrass production. Table 3 and Figure 1 illustrate the sensitivity analysis and probable impact on switchgrass yield and percentage of field conversion, respectively.

Table 3. Switchgrass breakeven prices by yield, 11 fields ($/ton) (Soldavini & Tyner, 2017)



	Without land costs			*With land costs*			
Switchgrass mature yield (ton ac^{-1})	Minimum ($ ton^{-1})	Maximum ($ ton^{-1})	Average ($ ton^{-1})	Minimum ($ ton^{-1})	Maximum ($ ton^{-1})	Average ($ ton^{-1})	Standard deviation ($ ton^{-1})
s4.5	$121.50	$157.60	$129.81	$200.75	$236.85	$209.06	$10.13
6	$107.38	$134.46	$113.61	$166.82	$193.89	$173.05	$7.60
7.5	$98.91	$120.57	$103.90	$146.46	$168.12	$151.45	$6.08
9	$92.23	$111.31	$97.42	$131.86	$150.94	$137.04	$5.07

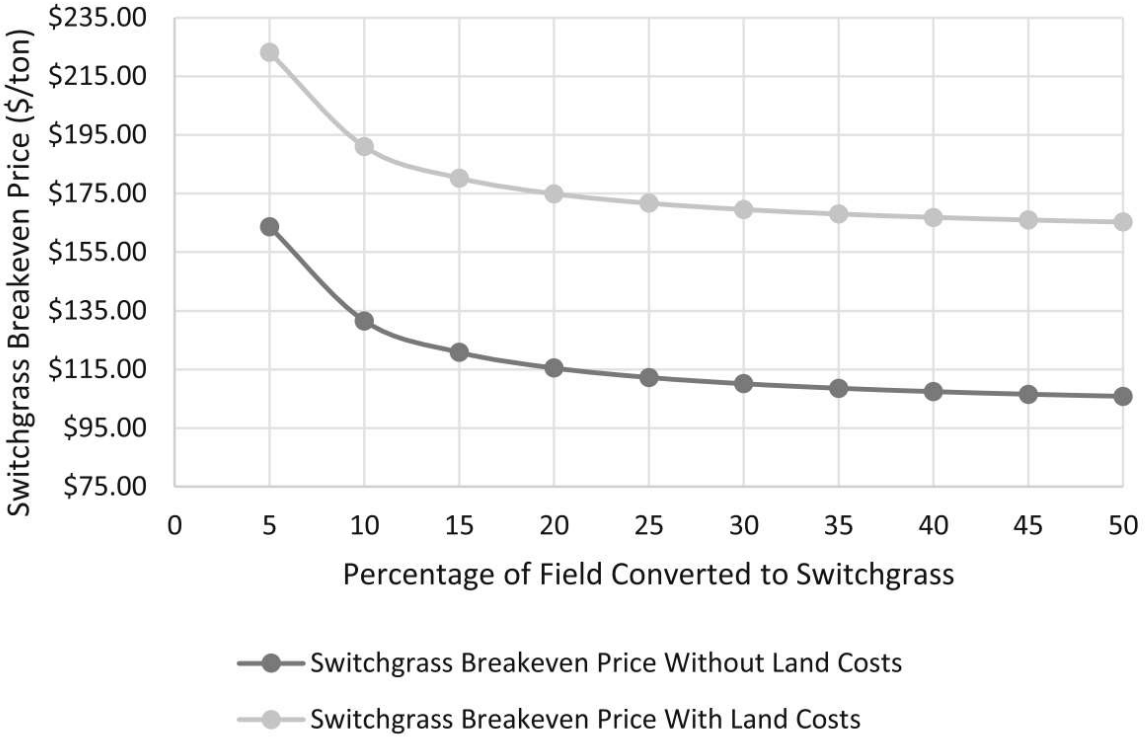


Figure 1. Switchgrass breakeven price by switchgrass conversion rate (% of field) (Soldavini & Tyner, 2017)

Overall, these results coupled with additional stochastic analysis presented in our journal paper (Soldavini and Tyner, 2017) show that there are some cases where targeted integration of a bioenergy crop like switchgrass into a farmer's production process may be economically viable. However, for most of the cases we investigated for this landscape design study, our results show that costs associated with incorporating switchgrass were substantially greater than other cropping systems. This suggests that farmer adoption of landscape design systems will likely require some form of environmental payment to induce farmers to make the cropping system change.

Reference

Soldavini, S., & Tyner, W. E. (2017). Determining Switchgrass Breakeven Prices in a Landscape Design System. BioEnergy Research, 11(1), 191-208. doi:10.1007/s12155-017-9888-6

No. 15. Landscape Design Effects on Agricultural Machinery Use Efficiencies

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Adoption and implementation of Landscape Design principles by producers will be highly dependent on the economic costs, and ability of producers to implement recommended field management changes without adversely affecting timeliness of field operations. In many cases, producers have a very limited time window to complete necessary field operations. This has caused producers to increase both size and capacity of their machines to ensure sufficient capacity to complete all field operations, such as tillage, planting, spraying and harvest, in a timely manner. Unfortunately, those high-capacity machines are most efficient when used in large rectangular fields. Thus, machine field efficiencies decrease significantly as production areas become smaller and more irregular in shape. To be accepted and implemented, Landscape Design principles must include factors that minimize reductions in field efficiency for every machine operation and subsequent machinery cost.

This case study was designed to quantify field geometry effect on the efficiency of grain harvest. It included:

a. Calculation of "Ideal" Harvest Field Efficiency for perfectly square or rectangular fields fractional sections thereof. Meeting those criteria will maximize potential field efficiency, since the only delays would be from the 180º turns at the end of each set of rows.
b. Determination of Actual Harvest Field Efficiency for irregular fields using GPS yield monitor data to account for actual harvest time and any delays between active harvest data, excluding those greater than 100 seconds.
c. Development of statistical models to predict Ideal Harvest Field Efficiency and Actual Harvest Field Efficiency based on field size, field geometry parameters and crop yield.
d. Estimation of differences in Harvest Combine costs for fields with harvest efficiencies in the upper 75% quartile compared to those in the lower 25% quartile.
e. Development of recommendations for Landscape Design principles that minimize decreases in machine field efficiencies and increase machinery costs.

Combine Yield Monitor files were obtained from collaborators managing 34 fields in northeast Indiana that ranged in size from 20 to 120 acres. Those fields would correspond to approximately 1/32 of a Section (1/4 mile by 1/8 mile) up to a nominal quarter Section (½ mile by ½ mile or 160 ac.). Data from those Indiana fields provided an ideal test case to estimate field efficiencies associated with Landscape Design principles because those areas were more likely to include irregular shapes and occlusions than harvest data from Iowa fields which were generally closer to ideal rectangles. Parameters extracted from the yield data files included: Harvested Field Area, Yield, Harvest Speed, Field Boundary Area (including occlusions), Field Headland Area, Active Harvest Time, Effective Swath Width, Turning Time, and other time delays. The Nominal Section Length and Nominal Section Width for each field was based on the Minimum Fraction Section Area (i.e., 160, 120, 80, 40, or 20 acres) rounded up to the nearest 1/8 of mile, required to encompass the field within the specified Sectional Area. The actual field harvest efficiency was calculated based on actual harvest area, active harvest time, turning and other time delays of 100 seconds or less (ASABE Standard EP496.3, 2020). It was assumed that any delay greater than 100 seconds was not a consequence of irregular turns or driving around field occlusions. Stepwise and Standard Linear Regression Models were used to determine which parameters (and interactions) were significant for prediction of Ideal and Actual Field Harvest Efficiency.

National Agricultural Statistics Service (NASS) data was used to determine the harvested crop area for Corn and Soybean, by Operator size, based on 2017 Census data for the State of Iowa. That NASS Data showed approximately 56% of the harvested land was in corn and 44% was in soybean in 2017. Estimated Harvest Machinery Costs per year were estimated for four different size operations (500, 2000, 5000, 10000 acres) assuming all producers had planted 56 and 44% of their total acres in corn and soybean, respectively. Machinery costs were estimated based on ASABE Machinery Management Standards (ASABE Standard EP496.3, 2020; ASAE D497.7, 2015). OEM 2020 machinery list prices for Series 6, 7, 8, and 9 Combines and Headers were used to estimate the purchase price for those machines, assuming that cost was 85% of the list price. Useful machinery life for the combines was estimated to be 3000 hours provided that level of use occurred in 12 years or less, which is assumed to the maximum life without replacement. The Machinery Harvest costs for the different operations were estimated based on three field efficiency parameters: (1) Ideal Harvest Field Efficiency for the relevant field size, (2) An actual Harvest Field Efficiency that averaged in the upper 75% quartile, or (3) An actual Harvest Field Efficiency that averaged in the lower 25% quartile.

Statistical regression model results for the Field Efficiencies are shown in Figures 1 and 2. Field Efficiencies for an “Ideal” field are highly leveraged by the length and width (i.e., field size) with a significant advantage given to longer field lengths because of reduced turning time. The Actual Field Efficiency could be predicted with reasonable accuracy by including an interaction term for the field area and headland buffer area for each field. In this case, headland buffer areas were assumed to be along the field edge and around any occlusions in the field that were not in the normal row planting direction. The headland to field area interaction provided a relatively simple parameter that accounted for several different field geometries.

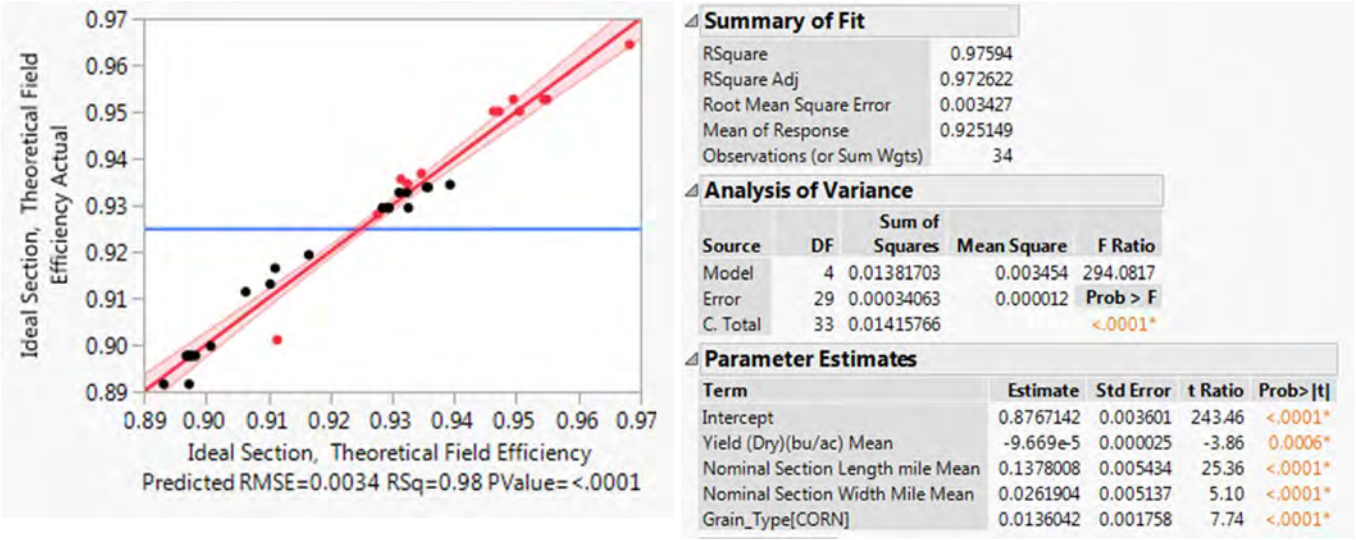
A comparison of ideal theoretical and actual (measured) field Harvest Field Efficiencies is presented in Tables 1 and 2. The actual measurements are highly variable with the highest quartile fields being almost equivalent to ideal sectional efficiencies and the lowest 25% quartile being more than 30% lower than the ideal field efficiencies. The significant effect of field geometry on field efficiency is clearly demonstrated by two fields of almost equal size (Figure 3) which showed 89.2 and 58.3% efficiency, respectively. This change in Field Harvest Efficiency had a significant effect on combine harvest cost.

Estimated harvest machinery costs for the different size operations, based on the ASABE Machinery Management Standards (ASABE Standard EP496.3, 2020; ASABE D497.7, 2015), are presented in Table 3. Changes in field efficiencies resulted in a 2 to 60% increase in machinery cost for harvest. The increased costs are primarily due to decreased field efficiency that ultimately requires either an additional combine or an increase in combine size to complete harvest in a timely manner. This analysis was based on the maximum available working hours between September 15 and November 15, which for an average of five harvest seasons (NASS Data, Iowa 2015-2019) ranged from 5 to 95% complete.

We conclude that Landscape Design principles must include factors to minimize the reduction in field efficiency of machinery operations and the resultant increase in machinery cost. Therefore, the following principles should be considered in the Landscape Design Process:

1) Fields with the longest lengths of travel will have the highest efficiency and field efficiency will be decreased significantly as field size decreases.
2) Any obstruction that splits the length of travel within a field will result in a very high reduction in harvest efficiency. Splitting fields in the width direction will have a significantly lower effect provided it does not occupy a significant portion of the field area. This is related primarily to an increase in the number of Headland turns.
3) Contiguous headland zones have less effect than separated headland turn zones in a field. In addition, the ratio of headland area to field area is a significant factor in the prediction of Field Efficiency. This index appears to represent the complexity of geometry fairly well.

Finally, even though Landscape Design principles could significantly increase machinery costs, including these principles in the design to minimize reductions in machine field efficiency and productivity could minimize those effects, thus increasing adoption of the practices by producers.



Summary of Fit

RSquare	0.97594
RSquare Adj	0.972622
Root Mean Square Error	0.003427
Mean of Response	0.925149
Observations (or Sum Wgts)	34

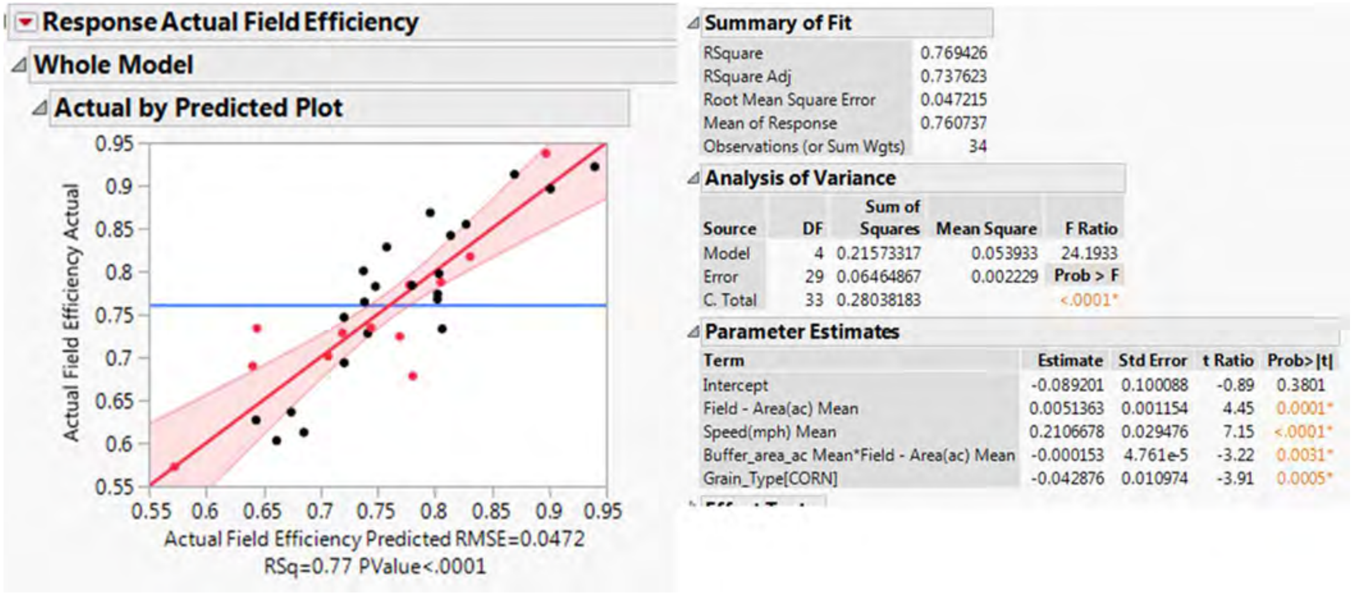
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	0.01381703	0.003454	294.0817
Error	29	0.00034063	0.000012	Prob > F
C. Total	33	0.01415766		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.8767142	0.003601	243.46	<.0001*
Yield (Dry)(bu/ac) Mean	-9.669e-5	0.000025	-3.86	0.0006*
Nominal Section Length mile Mean	0.1378008	0.005434	25.36	<.0001*
Nominal Section Width Mile Mean	0.0261904	0.005137	5.10	<.0001*
Grain_Type[CORN]	0.0136042	0.001758	7.74	<.0001*

Figure 1. Results of Prediction Model for estimated Field Efficiency for Ideal sub-sectional fields


Response Actual Field Efficiency

Whole Model

Actual by Predicted Plot

Summary of Fit

RSquare	0.769426
RSquare Adj	0.737623
Root Mean Square Error	0.047215
Mean of Response	0.760737
Observations (or Sum Wgts)	34

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	0.21573317	0.053933	24.1933
Error	29	0.06464867	0.002229	Prob > F
C. Total	33	0.28038183		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.089201	0.100088	-0.89	0.3801
Field - Area(ac) Mean	0.0051363	0.001154	4.45	0.0001*
Speed(mph) Mean	0.2106678	0.029476	7.15	<.0001*
Buffer_area_ac Mean*Field - Area(ac) Mean	-0.000153	4.761e-5	-3.22	0.0031*
Grain_Type[CORN]	-0.042876	0.010974	-3.91	0.0005*

Figure 2. Results of Prediction Model for Actual Field Efficiency from Harvested Fields in northeast Indiana

Table 1 Summary Comparison of Theoretical and Actual Harvest Efficiency among the Soybean fields

Field	Field Dimensions (ft, ac, mile)						Theoretical Ideal Harvest Efficiency		Actual Harvest Efficiency		Percent Reduction
	Boundary Length (ft)	Field Area	Headland Buffer area	Harvested Area	Nom. Length	Nom. Width	Ideal Eff.	Predicted Eff.	Measured	Predicted Eff.	
Field 1	3,620	15.9	4.7	14.5	1/4	1/8	0.892	0.897	0.603	0.676	32.4%
Field 2	3,411	14.8	4.4	13.6	1/4	1/8	0.892	0.893	0.613	0.701	31.3%
Field 3	6,606	31.3	8.7	29.4	1/3	3/8	0.913	0.910	0.636	0.683	30.3%
Field 4	5,893	22.3	7.8	20.6	1/4	1/4	0.898	0.897	0.627	0.656	30.2%
Field 5	8,711	35.6	11.4	32.1	1/2	1/8	0.929	0.929	0.694	0.730	25.4%
Field 6	5,998	26.5	7.9	24.4	1/2	1/8	0.929	0.929	0.733	0.817	21.1%
Field 7	5,744	28.5	7.5	26.8	1/2	1/8	0.929	0.928	0.747	0.730	19.7%
Field 8	4,416	21.9	5.8	19.8	1/4	1/4	0.898	0.898	0.728	0.753	18.9%
Field 9	6,951	60.7	9.3	58.8	1/2	1/4	0.933	0.931	0.768	0.798	17.7%
Field 10	8,375	35.9	7.5	32.5	1/3	1/4	0.911	0.906	0.774	0.808	15.1%
Field 11	8,645	37.8	11.7	35.5	1/4	1/4	0.898	0.898	0.765	0.747	14.8%
Field 12	9,663	57.4	12.9	53.3	1/2	1/2	0.934	0.939	0.797	0.806	14.7%
Field 13	5,073	29.5	6.7	27.8	3/8	1/8	0.916	0.911	0.784	0.788	14.5%
Field 14	4,267	19.2	5.6	17.5	1/4	3/8	0.900	0.901	0.783	0.761	13.0%
Field 15	7,044	15.7	8.6	13.3	3/8	1/5	0.919	0.917	0.801	0.754	12.9%
Field 16	16,297	79.6	21.3	73.6	1/2	3/8	0.934	0.936	0.842	0.824	9.8%
Field 17	7,161	33.9	9.4	31.4	1/2	1/8	0.929	0.930	0.855	0.836	8.0%
Field 18	4,783	28.3	6.3	26.4	1/4	1/4	0.898	0.897	0.828	0.766	7.7%
Field 19	7,440	62.5	9.9	57.8	1/2	3/8	0.934	0.936	0.896	0.897	4.0%
Field 20	5,014	29.8	6.6	28.9	1/4	1/4	0.898	0.897	0.868	0.804	3.3%
Field 21	8,234	38.9	10.9	35.8	1/2	1/8	0.929	0.933	0.913	0.877	1.8%
Field 22	8,538	23.8	10.1	26.6	1/2	1/8	0.929	0.929	0.915	0.735	1.6%
Field 23	10,608	67.4	13.8	63.3	1/2	1/4	0.933	0.932	0.922	0.940	1.1%

Table 2. Summary Comparison of Theoretical and Actual Harvest Efficiency among the cornfields.

Field	Field Dimensions (ft, ac, mile)						Theoretical Ideal Harvest Efficiency		Actual Harvest Efficiency		Percent Reduction
	Boundary Length (ft)	Field Area	Headland Buffer area	Harvested Area	Nom. Length	Nom. Width	Ideal Eff.	Predicted Eff.	Measured	Predicted Eff.	
Field 1	14,710	81.5	26.5	70.5	1/2	1/2	0.953	0.949	0.573	0.583	39.9%
Field 2	11,174	68.2	18.3	63.9	1/2	1/4	0.950	0.946	0.678	0.778	28.6%
Field 3	9,994	33.7	15.9	31.1	3/8	1/4	0.935	0.932	0.690	0.644	26.2%
Field 4	9,532	69.4	16.9	66.5	3/4	1/6	0.964	0.968	0.728	0.714	24.5%
Field 5	6,452	20.4	10.2	18.6	3/8	1/8	0.928	0.928	0.701	0.711	24.4%
Field 6	7,678	33.4	13.4	31.0	1/2	1/4	0.950	0.947	0.724	0.771	23.8%
Field 7	7,352	47.3	12.9	45.5	3/8	3/8	0.937	0.935	0.734	0.640	21.7%
Field 8	3,722	18.6	6.2	17.3	1/4	1/5	0.901	0.911	0.735	0.748	18.5%
Field 9	12,793	112.8	22.4	109.4	1/2	1/2	0.953	0.954	0.788	0.803	17.3%
Field 10	7,127	40.4	12.5	38.4	3/8	1/3	0.936	0.931	0.784	0.776	16.2%
Field 11	8,911	35.8	11.6	33.5	1/2	1/4	0.950	0.951	0.817	0.830	14.0%
Field 12	11,445	95.5	19.9	92.8	1/2	1/2	0.953	0.955	0.937	0.892	1.6%

Figure 3. Harvest Map for fields with the low (Left, Field Efficiency 58.3%, Harvested Field Area 70.5 ac) and high (Right, Field Efficiency 93.7%, Harvested Field Area 92.8 ac) measured harvest field efficiencies

Table 3: Estimated Combine Harvest costs for three different field efficiencies (Ideal Sectional Fields, Lower 25% Quartile Fields, Upper 75% Quartile Fields) within four farm operation sizes (500, 2000, 5000, 10000 acres)

	Operation Size (acres)			
	500	2000	5000	10000
"Ideal Field Efficiency"				
Field Efficiency Corn	0.96			
Field Efficiency Beans	0.93			
Combine Class	6	7	9	9
No. Combines	1	1	1	2
Avail. Working Hours	256	256	256	256
Combine Hours (Year)	50	154	228	228
Combine Harvest Cost ($/ac)	$112.24	$42.87	$26.88	$26.86
"Lower Quartile Field Efficiency"				
Field Efficiency Corn	0.6680			
Field Efficiency Beans	0.6790			
Combine Class	6	7	9	9
No. Combines	1	1	2	3
Avail. Working Hours	256	256	256	256
Combine Hours (Year)	70	218	161	214
Combine Harvest Cost ($/ac)	$119.25	$50.69	$44.91	$38.92
Percent Increase in Harvest Cost	6.24%	18.24%	67.10%	44.88%
"Upper Quartile Field Efficiency"				
Field Efficiency Corn	0.7760			
Field Efficiency Beans	0.8390			
Combine Class	6	7	9	9
No. Combines	1	1	2	3
Avail. Working Hours	256	256	256	256
Combine Hours (Year)	59	183	135	179
Combine Harvest Cost ($/ac)	$115.44	$46.36	$41.71	$35.47
Percent Increase in Harvest Cost	2.85%	8.15%	55.17%	32.04%

No. 16. Potential Water Quality Impacts of Watershed-Scale Biomass Production

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Overview

The multifactor Agricultural Conservation Planning Framework – Soil and Water Assessment Tool (ACPF-SWAT) was used to evaluate various landscape design scenarios for conservation-based cellulosic biomass production at the watershed scale on potential water quality impacts. The ACPF tool includes conservation planning guidelines for nutrient reduction at field, farm, and watershed scales and can be used to develop and support databases for watershed and other planning applications (Tomer *et al.*, 2015b). This study focused on biomass production and potential water quality and quantity impacts at the watershed scale within the South Fork of the Iowa River Watershed (SFIRW) and headwaters of the Raccoon River Watershed (HRRW). Implementation of conservation practices and landscape design scenarios with different biomass feedstocks were shown to have the potential to significantly improve water quality and support sustainable biomass production.

Introduction

We developed cellulosic biomass production scenarios based on implementing conservation practices that included: (1) conversion of marginally profitable row-crop land to switchgrass, (2) installing riparian buffers, saturated buffers, and grassed waterways, and (3) harvesting corn stover from fields with winter cover crops. The scenarios were chosen because (i) planting switchgrass on marginal lands [i.e., those having a low return on investment (ROI) for row crops] illustrates the use of profitability indicators for landscape design, (ii) vegetative barriers (i.e., multi-purpose buffers) can improve infiltration, trap nutrients and reduce sediment loss associated with runoff from cropland, (iii) saturated buffers can remove nitrogen, phosphorus, and trap sediments carried by drainage water when diverted through riparian buffers installed between crop fields and adjacent waterbodies, and (iv) planting winter cover crops can reduce runoff, erosion, nutrient losses and depletion of soil organic matter that can occur with excessive corn stover removal (Dabney et al., 2001).

SWAT (Arnold et al., 2012) was used to simulate potential changes in nutrient, suspended sediment, and streamflow for various biomass production scenarios implemented using conservation practices defined for different landscape designs by the ACPF. The unique contributions of this work are: (1) it presents a way to evaluate conservation practices incorporated into a landscape design using a modeling framework that includes the ACPF Toolbox, SWAT model, and decades of field monitoring data, and (2) it evaluates water quality effects of landscape design scenarios designed to incorporate cellulosic biomass feedstock production into marginally profitable or low productivity landscapes.

Method

Development of SWAT Model Application

SWAT is a physically based model that simulates hydrology and water quality for different conservation practices. Multiple data layers representing land topographic characteristics, soil types, stream networks, climate patterns, land uses, and crop choices were collected from national USDA and USGS, and NOAA NCDC databases. Daily weather data were provided from 1993 to 2016. Additional climate data, such as wind speed and relative humidity, were generated by the SWAT. The data sets were delineated into HUC 12 sub-watersheds and laid out in the SWAT model's hydrologic response units (HRUs) which represent areas with unique land use, soil, and slope. Crops were rotated every four to six years based on cropland database information from USDA and ACPF datasets. Figure 1 shows the historical land use map for the SFIR and HRRW.

Crop management practices simulated in SWAT include fertilizer application, tillage and tile drainage. Phosphorus fertilizer applications rates were obtained from the USDA's Economic Research Service. Nitrogen fertilizer rates were modeled based on nitrogen deficiencies in crop growth. Areas where manure was applied to corn within each watershed area was identified using information from the Iowa Department of Natural Resources (IDNR). Three different tillage strategies (no till, reduced tillage, and conservation tillage) were simulated using guidelines for each from CTIC (the Conservation Technology Information Center). Reduced tillage is currently the dominant practice within both watersheds (>75% for corn and >84% for soybean). Tile drainage was incorporated into the simulations based on tile drainage map information from IDNR's NRGIS library to RRW; and to the agricultural land with slopes of less than 5% where drainage maps within the SFIR and RRW did not exist or could not be found.

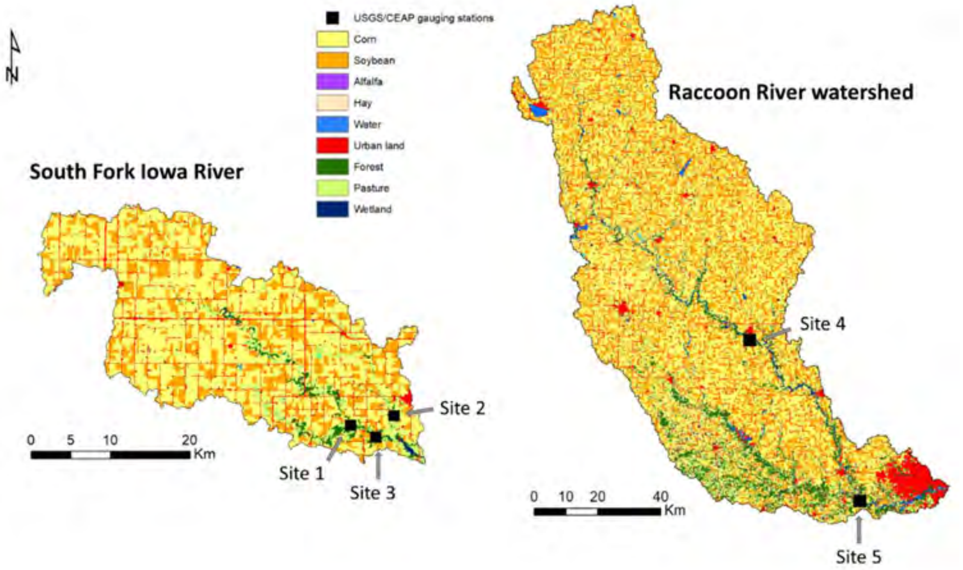

Figure 1. Land use map and locations of five water monitoring stations in the SFIR and RRW.

SWAT was calibrated and validated for stream flow, nitrogen, phosphorus, and suspended sediment using all available monitoring data for 20 years (1996 – 2015 for SFIR; 1997 - 2016 for RRW). Historical flow, nutrients, and sediment records at five measuring sites were obtained from USGS gauging stations (20 years), the SFIR Conservation Effects Assessment Project (CEAP) database from the USDA's Agricultural Research Service (ARS) (15 years), and additional data from Des Moines River water quality network for the RRW. For the latter (RRW), SWAT was calibrated for nitrate, nitrite, and organic N using data from site 5. Model performance was evaluated according to standard methods (Nash and Sutcliffe, 1970; Gupta et al., 1999).

Areas where 90-m wide riparian buffers could be imposed were identified using the ACPF and imported into SWAT at the HUC-12 scale. This resulted in a total riparian buffer area of 55.4 km^2 for the SFIR and 21.3 km^2 for the HRRW. Potential saturated buffer areas and grassed waterway acres were also based on ACPF results. A detail description of the SWAT model simulation parameters is available in Ha et al. (2020).

Production Scenarios

We compared three vegetative barriers: riparian buffer (RB), saturated buffer (RBSB), and grassed waterways (GRSW), among which the RB technology is relatively mature, has modest cost, and can potentially provide a large volume of biomass. Eight conservation practice and biomass production scenarios (Table 1) were simulated. The RB scenario represents perennial vegetation (switchgrass) in the riparian buffers, while Scenarios STV30, STV45, and STV70 represent removal of corn stover from fields at rates of 30%, 45%, and 70%, respectively. Scenarios STV30_rye, STV45_rye, and STV70_rye also reflect 30%, 45%, and 70% stover harvest, but include a winter cereal rye cover crop planted after stover harvest. We chose to apply supplemental fertilizer at rates of 7.7 kg N and 2 kg P per dry ton of stover harvest (Demissie et al., 2012). Within the model, cover crops planted after corn or soybean harvest were subsequently killed before planting the next crop. As illustrated in Figure 2, marginal land with the lowest ROI was chosen for conversion to switchgrass. For reference, ROI values for the least profitable 10% of corn and soybean acreage in the SFIR and HRRW watersheds were <0.3875 and <0.475, respectively.

Table 1. Biomass production scenarios simulated using the SWAT model.

Scenario	Feedstock	Conservation Practice	Application		
			Applied Area	SFIR (km^2)	HRRW (km^2)
RB	Switchgrass	Riparian buffer	ACPF design	55	21
STV30	Corn stover	—	Ag lands	654	368
STV30_rye	Corn stover	Cover crop	Ag lands	654	368
STV45	Corn stover	—	Ag lands	654	368
STV45_rye	Corn stover	Cover crop	Ag lands	654	368
STV70	Corn stover	—	Ag lands	654	368
STV70_rye	Corn stover	Cover crop	Ag lands	654	368
SWG	Switchgrass	—	Low ROI areas	76	42

Results and Discussion

Spatial Distribution of Water Quality Changes under Three Buffer Types

Recommended RB, RBSB, and GRSW placements from the ACPF were applied to SWAT simulations for 5.5% to 15.7% of the agricultural and hay land at the sub-basin scale within the SFIR watershed. In response, nutrient and sediment loadings decreased by up to 1.14 t/ha of suspended solids (SS), 5.43 kg/ha (NO_3-N), 7.23 kg/ha (TN), and 2.07 kg/ha (TP) across the watershed (Figure 3). The reductions intensified downstream. RBSB was the most effective in reducing total nitrogen (7.23 kg TN/ha) and nitrate-N loadings (5.43 kg/ha), followed by RB (Figure 4). Nitrogen reductions by GRSW were limited. The three practices had a similar effect on sediment loadings, although they were slightly higher (1.14 vs. 0.98 t/ha) for RBSB and RB than for GRSW. Phosphorus changes among the three buffers were similar to those for suspended sediments, averaging 2.07 kg P/ha for RB and RBSB and 1.92 kg P/ha for GRSW. Overall, RBSB was the most efficient at removing nutrient loadings within the SFIR, thus demonstrating those practices can be effective in reducing the direct entry of sediments and nutrients there, as reported for numerous other watersheds (Ha et al., 2020).

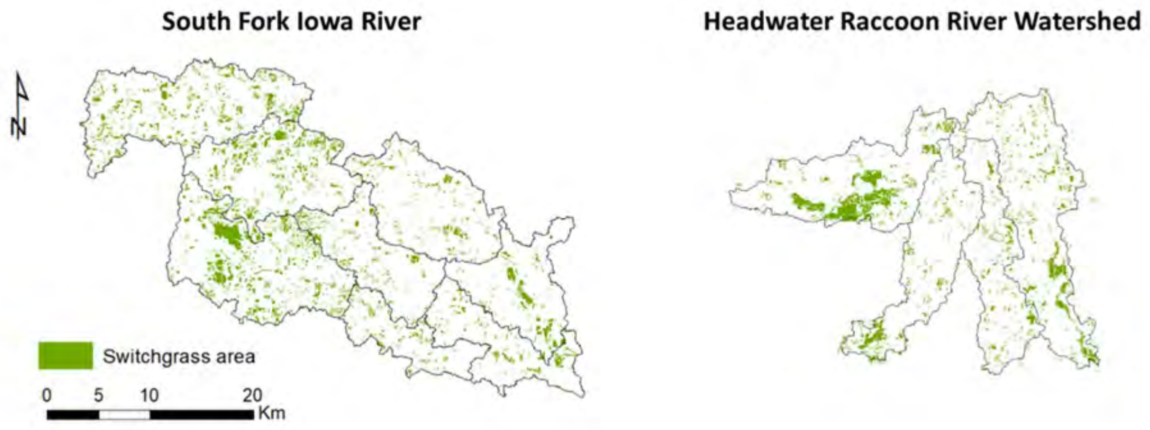

Figure 2. Potential sites for conversion to switchgrass (SWG) based on low ROI values.

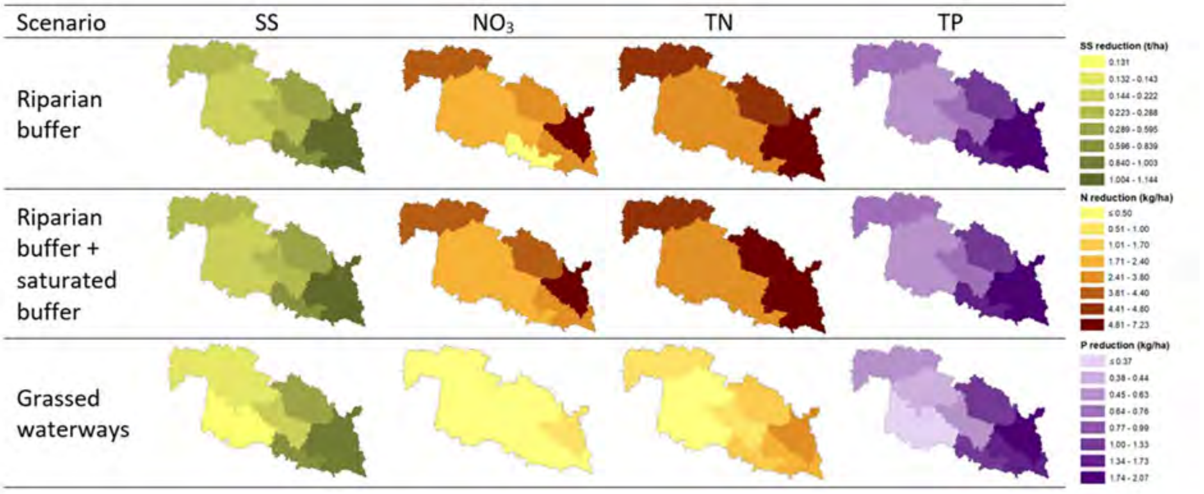

Figure 3. Spatial distribution of SS (t/ha), NO_3-N (kg/ha), TN (kg/ha), and TP (kg/ha) loading reductions after three buffer types (RB, RBSB, and GRSW) were applied to baseline scenario for the SFIR.

Biomass Production Scenario Impacts on Hydrology

Riparian buffer, stover removal, and switchgrass simulation scenarios using the SWAT affected water availability in different ways within the two watersheds as reflected by streamflow, water yield, soil moisture, and tile drainage. Compared with the historical baseline, streamflow was predicted to decrease by 0.3 to 6.4% in SFIR, and 1.4 to 11.7% in the HRRW under the eight scenarios (Table 2). Establishing RBs had the lowest impact on streamflow (0.3 to 1.4%). Harvesting 70% of the corn stover, especially with a cover crop can result in a 6.4 to 11.7% reduction in streamflow. Evapotranspiration (ET) tended to increase from 5.4 to 11mm annually in SFIR and 3.1 to 7.5mm in the HRRW as corn stover removal rates increased. The increase in ET in these scenarios reflects increased soil evaporation and decreased soil moisture due to less soil coverage. This also explains why water yield /streamflow decreases when stover removal rates are high. With a cover crop, soil evaporation was decreased due to increased soil coverage and the transpiration by rye also led to an increase in overall ET. Planting switchgrass on the marginal lands increased ET by 9.6 mm (SFIR) and 11.2 mm (HRRW), compared with the baseline (row crop) scenario. Therefore, producing this quantity of switchgrass would result in an ET similar to that for 30% stover removal. Furthermore, from a water balance perspective, an increase in ET loss would be associated with decreased water yield and tile flow. Finally, the degree to which the hydrology differs between the two watersheds is significant and hydrologic responses in RRW are pronounced. The HRRW has a relatively small land area (4 HUC12s) compared to the SFIR which has 8 HUC12s. The landscape stream network and soil type distributions are also different between the two watersheds.

Table 2. Average annual impact of bioenergy scenarios on streamflow, water yield, ET, and tile flow in SFIR and HRRW. Streamflow for SFIR was estimated at the outlet point, while the other values are for eight sub-basins (SFIR) or four sub-basins (HRRW).

	SFIR				**HRRW**			
Scenarios	**Streamflow**	**Water yield**	**ET**	**Tile flow**	**Streamflow**	**Water yield**	**ET**	**Tile flow**
	(cms)	**(mm)**	**(mm)**	**(mm)**	**(cms)**	**(mm)**	**(mm)**	**(mm)**
BASE	5.8	233	643	69	0.56	162	613	70
RB	5.8	233	643	69	0.55	162	613	70
STV30	5.7	227	649	66	0.54	159	616	68
STV45	5.6	225	651	64	0.54	157	618	67
STV70	5.5	222	654	62	0.53	155	620	65
STV30_rye	5.6	224	653	63	0.51	148	627	61
STV45_rye	5.5	221	655	62	0.50	146	629	60
STV70_rye	5.4	218	658	60	0.49	144	632	59
SWG	5.5	223	653	65	0.51	151	624	64

Impact of Biomass Production Scenarios on Water Quality

Temporal and geospatial variability in water quality indicators (SS, NO_3-N, and TP loadings) for baseline, RB, STV70_rye, and SWG scenarios were simulated with SWAT and averaged to provide monthly values at the HRU level for the SFIR and HRRW. Sediment-bound phosphorus loss per hectare over the growing season was substantially reduced by RBs, while SWG was projected to consistently reduce both nutrient and sediment loss by modest amounts. Water quality impacts of the STV70-rye scenario tended to fluctuate over time for both P and SS loss. Riparian buffers decreased predicted SS (0.093 and 0.047 t/ha) and phosphorus (0.177 and 0.098

kg/ha) loadings the most in June for SFIR and HRRW watersheds, respectively. Compared to the baseline, NO_3-N loading decreased in most months with RB, STV70_rye, and SWG management scenarios because of reduced runoff (Table 2). Nitrate (NO_3-N) loading for the STV70_rye scenario was significantly affected by March fertilizer application, mineralized N, and differences in the watershed characteristics.

Compared to baseline values, the STV70_rye scenario, which consisted of harvesting 70% of the corn stover and then planting a cover cover crop reduced the SS and phosphorus loadings during the non-growing season (Figure 4), but the losses increased from May to July/August. We suggest this response reflects the positive cover crop effects, even with a high stover harvest rate, during the October to April period, but after the cover crop was terminated and the corn crop was planted, runoff, sediment, and P losses increased until canopy closure when the soil surface was once again protected by vegetative cover.

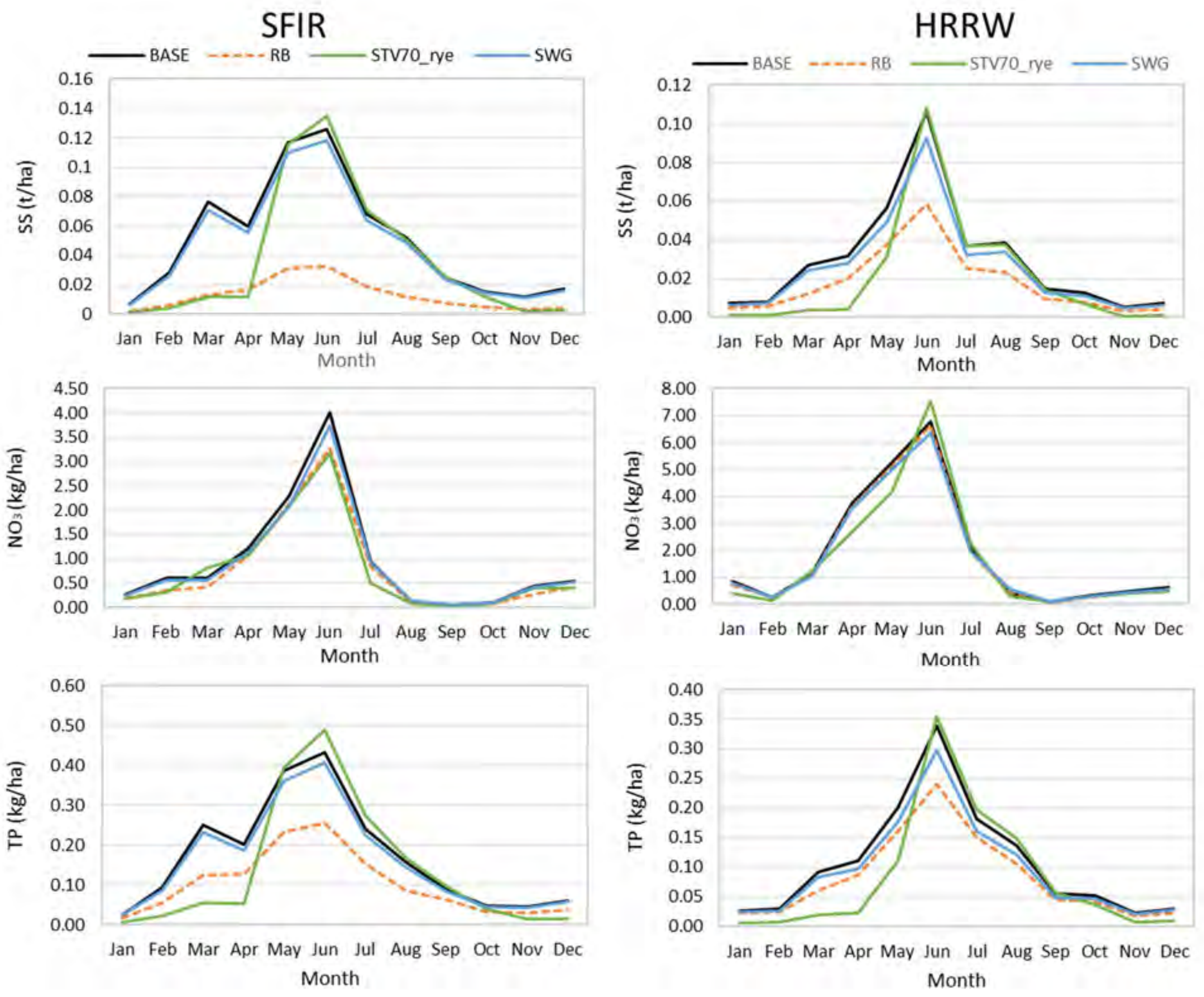

Figure 4. Temporal analysis of RB, STV70_RYE, and SWG conversion scenarios on average monthly SS, NO_3, and TP loadings compared to the historical baseline (BASE) values.

Figure 5 presents total annual reductions in nutrient and sediment loss for RB, stover removal, stover removal + cover crop, and SWG conversion scenarios. SWAT predictions for the RB scenario were reductions of approximately 17, 37, and 70% for N, P, and SS, respectively, in the SFIR, and 8, 25, and 60%, respectively, in the HRRW. Landscape design scenarios with stover removal (STV30/45/70) increased SS and P losses, but reduced N loadings compared to baseline values. SS loadings for the STV30/45/70 scenarios (i.e., no cover crop) increased because the soil was not protected from soil loss. Phosphorus loadings, especially insoluble P, also increased, presumably because of its attachment to soil particles. As stover harvest rates increased in the absence of a cover crop, SS loadings increased up to 3.8% for SFIR and 1.2% for HRRW, but with a winter cover crop (STV30/45/70_rye) large reductions in N, P, and SS loadings were projected for both watersheds. This is consistent for several other watershed studies (Gassman et al., 2017).

Figure 5. Impact of various bioenergy feedstock production scenarios on average N, P, and SS losses compared to baseline values at the outlet point in the SFIR or the weighted average of four HRRW sub-basins.

Biomass Production

Biomass harvest yields were calculated in SWAT following the warm-up (i.e., calibration) phase. Table 3 presents those predictions for average annual biomass production following conversion of low ROI land to SWG, harvesting, or establishing a riparian buffer in the SFIR or HRRW watershed. Switchgrass yields for RB scenarios were calculated based on the Water Analysis Tool for Energy Resources (WATER) model (http://water.es.anl.gov/). Biofuel production potential ranged from 10.2 to 75.6 million liters for the SFIR and from 3.3 to 35.3 million liters for the HRRW for the different scenarios. Biomass yields increased proportionally as stover harvest rates increased from 30 to 70%, the amount of residue left in the field was reduced. With 70% stover harvest, biomass feedstock per year was projected at 343,773 metric tonnes (7.3 t/ha) for the SFIR and 160,581 metric tonnes (7.8 t/ha) for the HRRW. Those amounts of feedstock could produce approximately 75.2 million liters of biofuel for the SFIR and 35.3 million liters of biofuel for the HRRW. Switchgrass plantings within the landscape designs were projected for approximately 9.5% of the SFIR (75.8 km^2) and 9.9% of the HRRW (41.6 km^2), which could potentially provide 16.9 and 8.8 million liters of biofuel, respectively. SWAT simulated corn grain yields (11.4 t/ha for SFIR and 12.1 t/ha for HRRW) were similar to the five-year (2002, 2007, 2012, 2016, and 2017) average values (10.7 to 11.6 t/ha) obtained for Buena Vista, Hamilton, Hardin, and Pocahontas counties from the USDA National Agricultural Statistics Service (https://quickstats.nass.usda.gov/).

Table 3. Biomass feedstock production and biofuel production potential for proposed landscape design scenarios in the SFIR and HRRW.

Watershed	**Scenario**	**Harvestable Feedstock (tonnes)**		**Biofuel Production (ML)** [†]
		Stover	**Switchgrass**	
SFIR	RB		46,250	10.2
	STV30	144,523		31.8
	STV45	217,710		47.8
	STV70	343,773		75.6
	STV30_rye	141,128		31.7
	STV45_rye	216,835		47.7
	STV70_rye	342,248		75.2
	SWG		76,952	16.9
HRRW	RB		15,116	3.3
	STV30	67,180		14.8
	STV45	101,210		22.2
	STV70	160,581		35.3
	STV30_rye	66,693		14.7
	STV45_rye	100,580		21.1
	STV70_rye	159,712		35.1

[†] Cellulosic biofuel ethanol is produced from switchgrass and corn stover via biochemical fermentation process with a yield of 80 gallons per dry short tone. Biomass loss 20% during the harvest.

Conclusions

Eco-hydrologic models such as SWAT are important tools for assessing landscape design impact on the effectiveness of watershed-scale land and crop management practices. With regard to the sustainability of bio-feedstock production, soil erosion, water availability, water quality, biomass production, and biodiversity impacts must all be examined. This Case Study summarizes results from simulations for two SWAT watershed models used in Iowa to simulate different landscape management scenarios with ACPF conservation practice guidelines. This included riparian buffers, saturated buffers, cover crops, stover harvest, and planting switchgrass in marginal lands. Our results suggest that biomass production through landscape design, multi-purpose buffer conservation practices, and residue management can provide cellulosic feedstock for biofuel production and improve water quality by reducing soil erosion, nitrogen and phosphorus losses to the waterbodies in the SFIR and HRRW. Energy crops grown on marginal land can provide biomass and water quality benefits. Simulated multi-purpose buffers and planting cover crops appear to be practical ways for mitigating nutrient and soil loss in the region. For the scenarios evaluated, nutrient and sediment losses were projected to be reduced 60 to 70% for SS (riparian buffer), 20 to 30% for nitrogen (stover harvest with cover crop), and 20 to 40% for phosphorus (riparian buffer and stover harvest with cover crops) compared to historical baseline conditions. With exception of the riparian buffer scenario, the simulations also projected potential water loss. Results and conclusions obtained from this SWAT modeling study would apply to regions with similar landscapes, climate, and soil conditions. The conservation practices are recommended by the State of Iowa and have begun to be adopted by landowners across the region. Overall, we conclude the results can contribute to decision-making for future biomass production that will provide energy, economic, and environmental benefits.

Literature Cited

Arnold, J. G., J. R. Kiniry, R. Srinivasan, J. R. Williams, E. B. Haney, and S. L. Neitsch. 2012. "Soil and Water Assessment Tool Input/Output Documentation: Version 2012." *Texas Water Resources Institute* 7.

Dabney, S. M., J. A. Delgado, and D. W. Reeves. 2001. "Using Winter Cover Crops to Improve Soil and Water Quality." *Communications in Soil Science and Plant Analysis* 32 (7-8): 1221–1250.

Demissie, Y., E. Yan, and M. Wu. 2012. "Assessing Regional Hydrology and Water Quality Implications of Large-Scale Biofuel Feedstock Production in the Upper Mississippi River Basin." *Environmental Science & Technology* 46 (16): 9174–9182.

Gassman, P. W., A. M. Valcu-Lisman, C. L. Kling, S. K. Mickelson, Y. Panagopoulos, R. Cibin, I. Chaubey, C. F. Wolter, and K. E. Schilling. 2017. "Assessment of Bioenergy Cropping Scenarios for the Boone River Watershed in North Central Iowa, United States." *Journal of the American Water Resources Association* 53 (6): 1336–1354.

Gupta, H. V., S. Sorooshian, and P. O. J. J. o. h. e. Yapo. 1999. "Status of Automatic Calibration for Hydrologic Models: Comparison with Multilevel Expert Calibration." 4 (2): 135-143.

Ha, M., M. Wu, M. D. Tomer, P. W. Gassman, T. M. Isenhart, J. G. Arnold, M. J. White, E. Parish, K. S. Comer, and B. Belden. 2020. " Biomass Production with Conservation Practices for Two Iowa Watersheds". Biomass Production with Conservation Practices for Two Iowa Watersheds. JAWRA. Paper No. JAWRA-20-0116-P. https://onlinelibrary.wiley.com/doi/10.1111/1752-1688.12880.

Nash, J. E. and J. V. Sutcliffe. 1970. "River Flow Forecasting through Conceptual Models Part I—a Discussion of Principles." *Journal of Hydrology* 10 (3): 282–290.

Tomer, M. D., S. A. Porter, K. Boomer, D. E. James, J. A. Kostel, M. J. Helmers, T. M. Isenhart, and E. McLellan. 2015b. "Agricultural Conservation Planning Framework: 1. Developing Multipractice Watershed Planning Scenarios and Assessing Nutrient Reduction Potential." *Journal of Environmental Quality* 44 (3): 754–767.

No. 17. Stream Water Quality Assessments within the Southfork Watershed of Iowa

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This Case Study summarizes activities specifically associated with a BioEnergy Technologies Office (BETO) funded project entitled "Spatially resolved measurements of water quality indicators within a bioenergy landscape" (WBS 4.2.2.44) that is independent of, but highly complementary to this Landscape Design project. The specific objectives of 4.2.2.44 are to:

1) Design, assemble, and test a novel unmanned surface vehicle (USV)-water quality sensor platform to enhance understanding of water quality indicators for bioenergy.
2) Use the USV-water quality platform to improve understanding of spatiotemporal variability in water quality parameters in an agricultural-bioenergy landscape, including to assess the efficacy of saturated buffers at reducing nutrient inputs from agricultural fields to streams.

The USV-water quality measurement platform ("AquaBOT") was designed, assembled, and tested by Oak Ridge National Laboratory (ORNL) engineers and scientists to evaluate effects of bioenergy feedstock plantings (e.g., perennial grasses) and various conservation practices (e.g., saturated buffers, cover crops) on water quality. Two water quality parameters [nitrate nitrogen (NO_3-N) and turbidity] were of primary interest because they are two common pollutants in Midwestern agricultural streams. Nitrate is important not only as a potential water quality contaminant, but also with regard to fertilizer use efficiency and production costs, while turbidity is an indicator of total suspended sediments and possibly total phosphorus. In FY20, the AquaBOT was brought to Iowa to map water quality along a reach of South Beaver Creek, Iowa, which is located within the Southfork Watershed.

In November 2019, a test run of the AquaBOT was conducted and preliminary measurements were collected. A more intensive sampling plan for 2020 was devised to assess the efficacy of the South Beaver Creek saturated buffers by collecting AquaBOT measurements upstream, within, and downstream of the saturated buffer reach (Figure 1). Unfortunately, logistical constraints due to the COVID-19 pandemic required a shift in field sites from the Southfork Watershed to the Fourmile Watershed (near Des Moines, Iowa). AquaBOT measurements were initiated in Fourmile Watershed during the summer of 2020 and will continue in 2021. This Case Study briefly describes the AquaBOT system and presents water quality mapping results from the South Beaver Creek saturated buffer reach that was evaluated in November 2019.

AquaBOT Design

The AquaBOT was designed to measure agriculturally relevant water quality parameters (i.e., nitrate concentration, turbidity) in small streams. All components on the AquaBOT were commercial off-the-shelf products (Table 1). The unit was a catamaran-style "HyDrone" (Seafloor Systems, Inc.) USV. It was chosen for its stability, high payload (35 lbs), and small size (116 cm length, 73 cm width) compared to most other commercially available USVs. This small size also enabled it to operate in fairly narrow and shallow waters (> ~1 ft water depth).

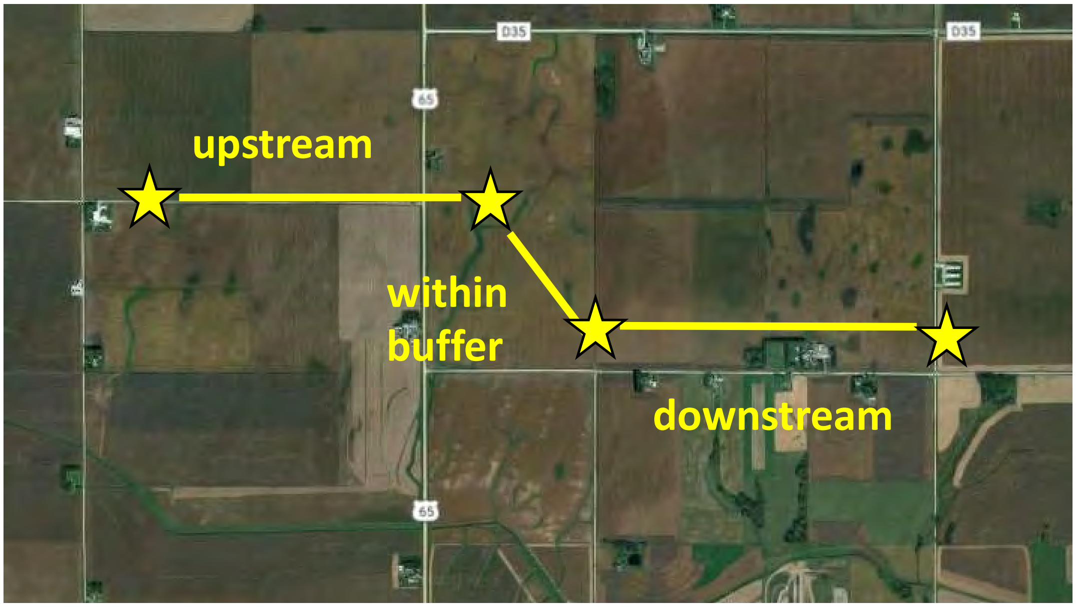

Figure 1 – Planned measurement reach of South Beaver Creek, Iowa. The objective was to assess the efficacy of saturated buffers at reducing nutrient inputs.

Table 1 – Components of the AquaBOT.

1. Unmanned surface vehicle (USV; *Seafloor HyDrone*)
2. Two 14.8 V 16 Ah LiPo batteries and charger (*Venom Professional UAV series*)
3. Nitrate sensor and accessories (*OTT HydroMet ecoN*)
4. Multiparameter sonde bulkhead and accessories (*YSI EXO1*)
5. Total algae sensor (for *EXO1*)
6. Conductivity/temperature sensor (for *EXO1*)
7. Optical dissolved oxygen sensor (for *EXO1*)
8. Turbidity sensor (for *EXO1*)
9. pH sensor *(for EXO1)*
10. Field cable and handheld (for *EXO1*; used for sensor calibrations)
11. GPS system (*AtlasLink GNSS Smart Antenna*)
12. Photosynthetically active radiation sensor (*LiCOR*)
13. Datalogger (*Campbell Scientific CR6*)
14. 12 V 12 Ah battery and charger
15. Accessories for USV assembly (e.g., clamps, rods, PVC enclosures, etc.)

The nitrate sensor (OTT ecoN sensor) was selected due to its high measurement accuracy, light weight, and smaller size than most other nitrate sensors. The multiparameter water quality sonde (YSI EXO1) was also selected for its smaller size and ability to measure multiple water quality parameters of interest (e.g., temperature, specific conductivity, dissolved oxygen, turbidity, total algae, pH). The YSI EXO1 has four sensor ports so the user can decide which water quality sensors to include based on their specific needs. A quantum sensor, measuring photosynthetically active radiation (LiCOR PAR meter), was included in the AquaBOT design to relate PAR to biologically relevant parameters (e.g., total algae). Geospatial data were collected using a GPS system (AtlasLink GNSS Smart Antenna), providing sub-meter location (latitude, longitude, elevation) data. All sensors on the AquaBOT were wired to one central datalogger (Campbell Scientific CR6), the output from which included data with a single time stamp from all three sensors (nitrate, water quality, PAR) and the GPS. Data were logged every minute. The datalogger was housed in a waterproof PVC cylinder, and a water-tight USB connection on the outside of the PVC allowed the user to directly connect a computer to the datalogger for data downloads. The datalogger was able to generate its own Wi-Fi signal so that in addition to internally logging the data, the data could be read in real-time on a mobile device using the "Logger Link" application from Campbell Scientific. Power for sensors and the datalogger came from a 12-volt, 12 Ah battery that was housed in a watertight box. The HyDrone USV was powered by two 14.8-volt 16 Ah LiPo batteries (Venom Professional UAV series). The weight of the USV and the USV batteries was 25 lbs and the payload on the USV was approximately 33 lbs, resulting in a total weight of 58 lbs (Figure 2).

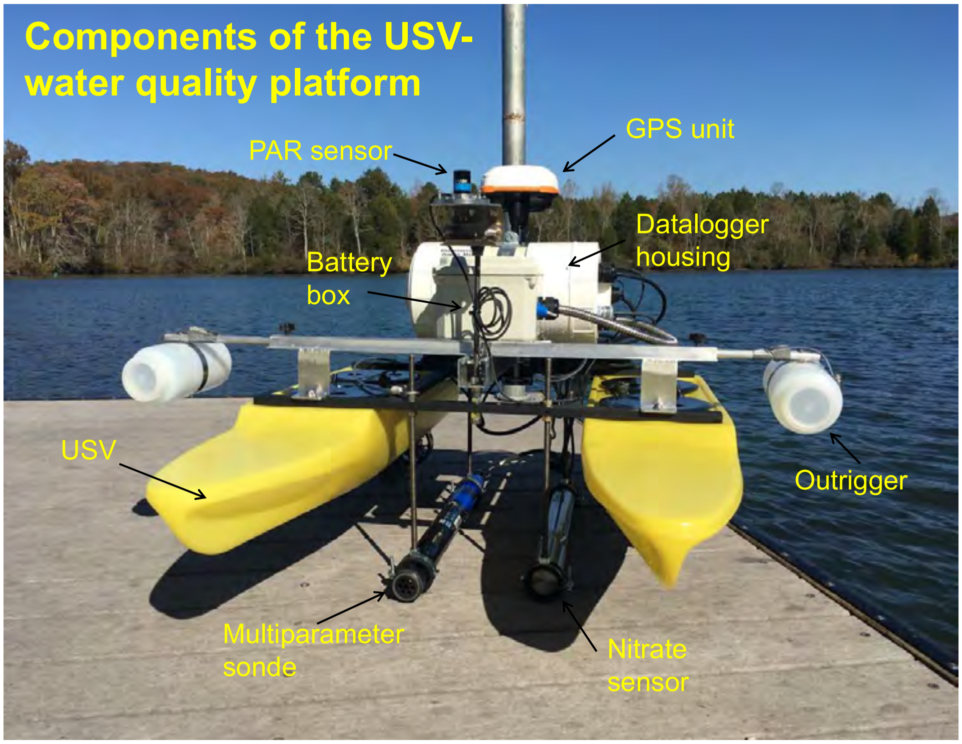

Figure 2 – The AquaBOT shown out of water. Outriggers were used to help stabilize the AquaBOT when operated in larger bodies of water or under conditions of high turbulence.

AquaBOT Measurements in South Beaver Creek, Iowa

An *in situ* test of the AquaBOT was performed along a 420 m reach of South Beaver Creek, Iowa (Figure 3) on November 14, 2019. A total of 48 measurements were collected by the AquaBOT during this deployment, which occurred from 12:06 to 12:53 (the datalogger was programmed to collect water quality data every minute). This equated to one measurement every ~8.75 m of stream length during this test run. The highly spatially resolved water quality measurements collected by the AquaBOT revealed spatial patterning in all physicochemical parameters measured, including temperature, dissolved oxygen, specific conductivity, nitrate concentration, and turbidity (Figure 4A-E).

Figure 3 – Deployment of the AquaBOT in the saturated buffer reach of South Beaver Creek, Iowa, on November 14, 2019.

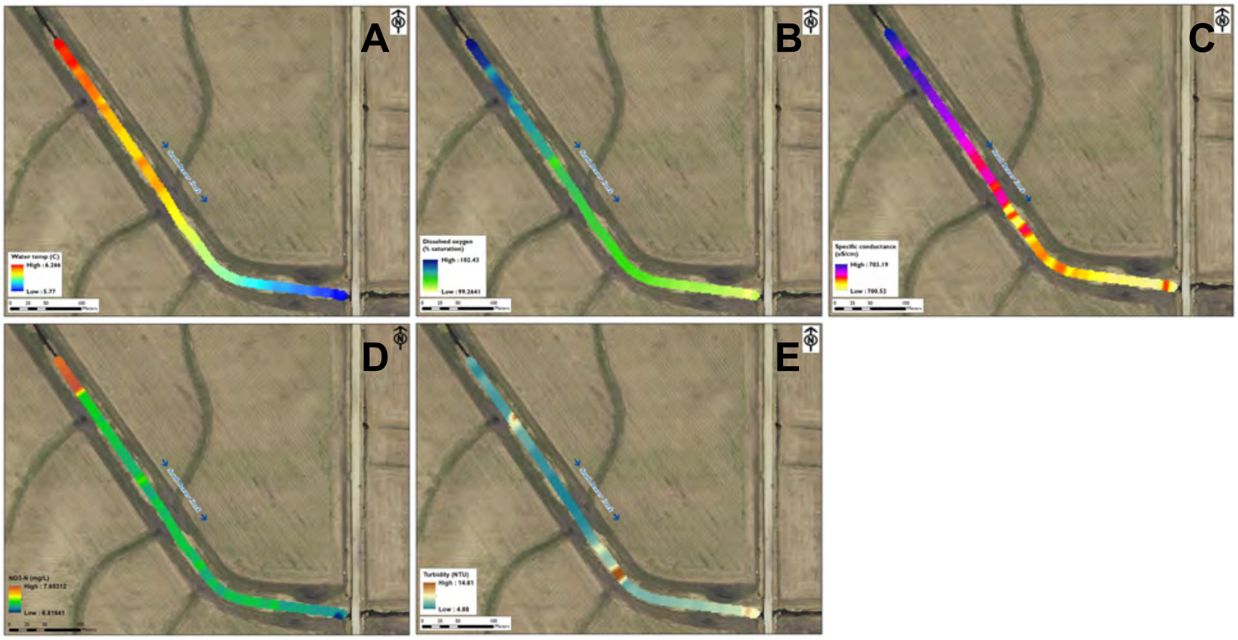

Figure 4 – Spatial patterns of (A) water temperature, (B) dissolved oxygen, (C) specific conductivity, (D) nitrate concentration, and (E) turbidity along a 420 m reach of South Beaver Creek, Iowa where a saturated buffer had been constructed in the riparian zone.

After the South Beaver Creek test run in November 2019, it was anticipated that the AquaBOT would be used to map water quality along much longer distances within the Southfork Watershed beginning in spring 2020. For example, we planned to measure water quality along a ~50 km stretch of the Southfork River to examine the patterning of water quality within a bioenergy/agricultural landscape and how water quality changes as a river flows through different land use types (i.e., row-crop agriculture, pasture, forested buffers). We also planned to use the AquaBOT to examine the efficacy of the saturated buffers installed in South Beaver Creek (Figure 1). However, the COVID-19 pandemic created unprecedented challenges for fieldwork so the field sites were shifted to Fourmile Creek Watershed (near Des Moines, Iowa). The two main objectives of this study will still be addressed in Fourmile Creek Watershed (i.e., saturated buffer efficacy, spatiotemporal variation in water quality).

AquaBOT Measurements in the Fourmile Creek Watershed, Iowa

"Spatially resolved measurements of water quality indicators within a bioenergy landscape" is a BETO-funded project that is independent of, but complementary, to the Landscape Design project. The objective of this project is to design, assemble, and deploy the AquaBOT to improve understanding of spatiotemporal variability in water quality parameters in streams draining an agricultural-bioenergy landscape.

In 2020, we began fieldwork in the Fourmile Watershed. Our focal field site is Alleman Creek, a 2nd-order stream in central Iowa that drains a predominantly agricultural (96% of land) watershed. In summer 2021, a total of 26 tile drains along a 2.3-km reach of Alleman Creek were removed and converted to saturated buffers, making this stream the site of one of the largest edge-of-field conversation practice trials in the state of Iowa. Our project is using multiple water quality measurement strategies to provide a comprehensive assessment of water quality responses to conservation practice implementation. These multiple water quality measurement approaches include fixed-point grab sampling (three sampling locations along the 2.3-km study reach), fixed-point sensor stations (two sensor locations, at the upstream and downstream ends of the study reach), and the AquaBOT (meter-scale measurements of water quality along the 2.3-km reach); we focus our brief discussion on the latter method here.

We carried out three AquaBOT runs in June 2020 and five AquaBOT runs from March through May 2021 in Alleman Creek; all AquaBOT data to date have been collected prior to saturated buffer implementation (installation = summer 2021). The AquaBOT method revealed meter-scale variation in water quality parameters along Alleman Creek. Using the AquaBOT, we observed high nitrate concentrations and low specific conductivity values downstream of tile drains, with the presence, magnitude, and direction (i.e., enrichment or dilution effect) of these values changing over time. Our AquaBOT data collection periods were restricted to periods of higher flow, and a regional drought that resulted in low to no stream flow precluded AquaBOT deployments in the summers of 2020 and 2021. We plan to continue our measurements in Alleman Creek in 2022, using the three methods described above, to evaluate saturated buffer efficacy.

Overall, our results to date suggest that measurements that only capture spatial or only capture temporal variability in water quality provide an incomplete picture as to the patterns and potential drivers of water quality in streams and rivers. Many water quality sampling programs typically collect water samples at a fixed location. Therefore, this sampling approach will likely miss these spatial patterns and will not be able to identify hotspots that may be related to point-source inputs. If resources only allow for fixed-location sampling, the AquaBOT could be used to help identify the most representative sampling location.

No. 18. Data Harvesting to Model Agroecosystem Impact of Landscape Design on Productivity and Environmental Performance at Field- and Watershed-Scales

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Background

Technological progress in recent years has increased availability and granularity of soil, climate, and agricultural management information for agricultural production fields. Advances in remote and proximal sensing promise an ever-increasing supply of data, including detailed on-farm operations collected via sensors installed in agricultural equipment that can report operational, soil, and crop conditions. One goal associated with this Landscape Design project is to harness and couple that data with simulation modeling tools that facilitate design and evaluation of agroecosystem landscapes *in silico.* The models and tools need to be transparently calibrated and then reused to develop informed decisions.

We used Cycles, a field-level one-dimensional agroecosystem model, to simulate the agricultural landscape of Iowa. Although we originally focused on the Racoon River South Fork Bend and North Raccoon Headwaters, field-scale simulations have been conducted for more than 870k fields covering all the cropland of Iowa. Innovations associated with this Landscape Design project were estimates of field-scale animal manure input using publicly available information about location of confined animal feeding operations (CAFOs) and livestock inventories. Improved animal manure management is an integral component of Landscape Design scenarios because of its potential impact on ecosystem services. Simulation modeling is one step toward increasing fidelity in representation of field and landscape dynamics using virtual tools.

Scenario definition

The Landscape Design team selected 48 scenarios that represented an escalating transition in terms of tillage intensity, nutrient management, corn residue removal, and vegetation cover. Conventional tillage was used as the baseline or reference for comparison, with reduced tillage and no-tillage as option for reducing the frequency and intensity of soil disturbance. Potential changes in nutrient management included rates and timing of nitrogen chemical fertilizer application. Crop residue management scenarios included four levels of harvest or removal (0, 30, 45, or 70%). Additional vegetation management included adding rye cover crops (that could be harvested for biomass) to corn-soybean rotations or planting switchgrass in subfield areas defined as having low economic return on investment (ROI) due to low crop yields. The low ROI fields and subfields were provided by Dr. Esther Parish at ORNL based on an analysis of data produced by AgSolver. Overall, we simulated 48 distinctive soil and crop management scenarios.

The Cycles model

Cycles is a user-friendly, multi-crop, multi-year, process-based agroecosystems model with daily time step simulations of crop production and the water, carbon (C) and nitrogen(N) cycles in the soil-plant-atmosphere continuum. The model evolved from C-Farm and is closely related to CropSyst. Cycles includes multiple innovations in agroecosystem simulation that are relevant to this project. Soil organic carbon (SOC) saturation is simulated because of its importance to both carbon and nitrogen balance when transitioning to no-till or in any system that inputs large amounts of residue to narrow soil layer. The model also enables the soil to be stratified, thus reflecting depth and intensity of tillage. Cycles can simulate any annual crop sequence with or without intercropping, as well as multi-species perennial stands. The model has been configured to run on the Penn State Computer Cluster, thus enabling it to efficiently handle millions of simulations. Outputs are printed in a form compatible with DataBrain™ demands for delivery as a web service.

Input development

Soil input data were obtained from G-SSURGO. The weather data, compiled at a daily time-step, was extracted from the North American Land Data Assimilation System (NLDAS) which provides gridded weather data (1/8th of a degree) from 1979 to present. Each field was derived from a common land unit (CLU) database, retaining only cropland. The CLU database was provided by Dr. Joshua Woodard at Cornell University. Although we have the actual rotations that occurred in each field in the time frame of interest for this project based on CropScape, we followed the project protocol by simulating 2013, 2014, 2015 and 2016 for this report. All combinations of soils and field were run to steady state using a reference management scenario that used conventional tillage and with a crop sequence in each field that agreed with the database provided by DataBrains™. By 1 Jan 2010, the soil variables, including soil carbon and mineral nitrogen distribution with depth, reflected steady state conditions. The result is that the delta between the reference and any alternative scenario depends on the weather of the simulated years and the attributes of the alternative scenario. The simulations considered the distribution of manure across the landscape as estimated for each field (Fig. 1). While accuracy cannot be expected at the field level, the uncertainty reduces as the aggregation level increases. We simulated 871,595 fields, accounting for approximately 29M acres, 5M of which received manure. The South Fork Bend and Headwater of the North Raccoon included 2,519 and 4,237 fields, respectively.

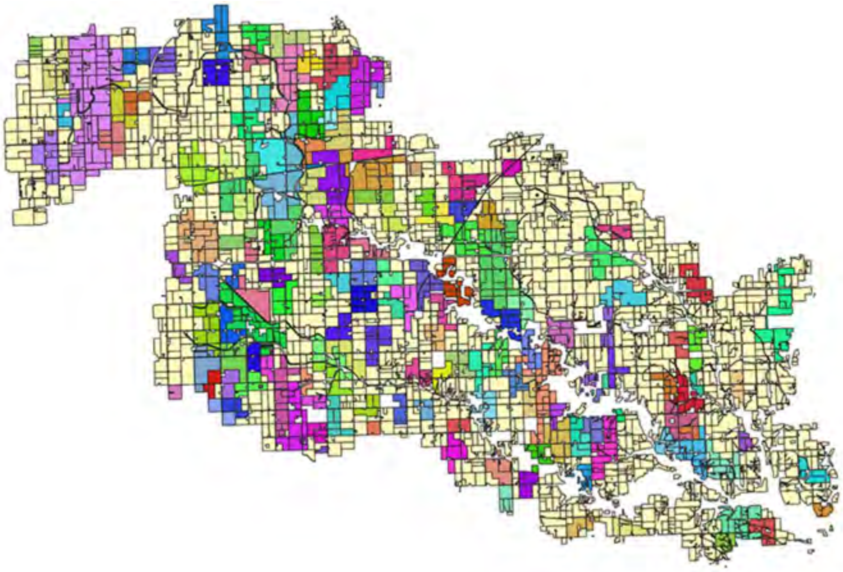

Figure 1. Manure distribution across fields in the South Fork Bend watershed. The colors distinguish CAFOs.

Output summary

On average, the results follow a somewhat expected pattern, but year-to-year variation in weather can mask average results. Split fertilizer application, as opposed to applying all fertilizer in spring, reduced leaching in most fields, with a few fields showing increases in leaching (Fig. 2). Corn stover removal may in some years decrease nitrate leaching but the results can vary substantially with location. Within the South Fork Bend and North Raccoon River headwaters, a 30% simulated stover removal resulted in roughly 50% decrease in nitrate leaching (this effect comes at the cost of higher exposure to erosion, we did not evaluate the tradeoff). Evaporation and its impact on soil drying and percolation are important drivers. Overall, wetter areas (i.e., the east side of Iowa) showed lesser effects of removing stover on N leaching. No-tillage increased yields in most cases, although the model may overexpress no-till benefits, as delays in planting date due to wetter soils were not simulated. On average, leaching increased in some no-till scenarios (roughly an additional 2 lb/ac/yr of N was lost in no-till compared to the tilled scenario*s*) because higher soil moisture creates more soil hydrological continuity. Erosion control, one of the advantages of high-residue and no-till farming was not simulated within these scenarios. Furthermore, when shifting to no-till, soil organic carbon increased in some locations and decreased in others within the four-year simulations (Fig. 3).

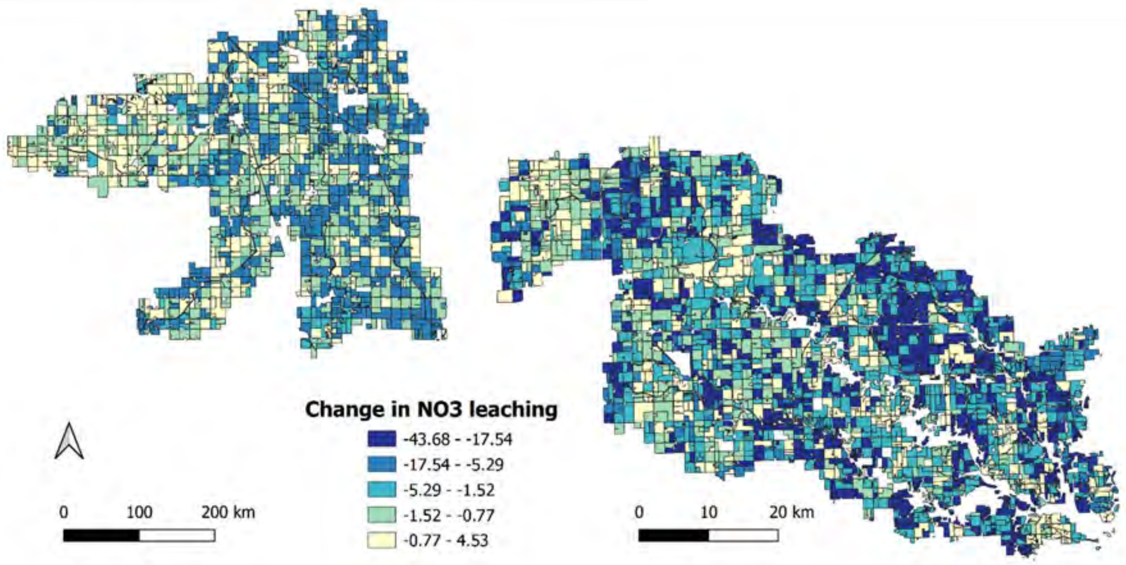

Figure 2. Simulated change in lbs of N/ac NO3 leaching by using a split fertilizer application. Fields are given 220 kg of N/ha and a 20 kg/ha fertilizer starter. The yellow color signals no change in leaching, and the blue and green leaching reductions.

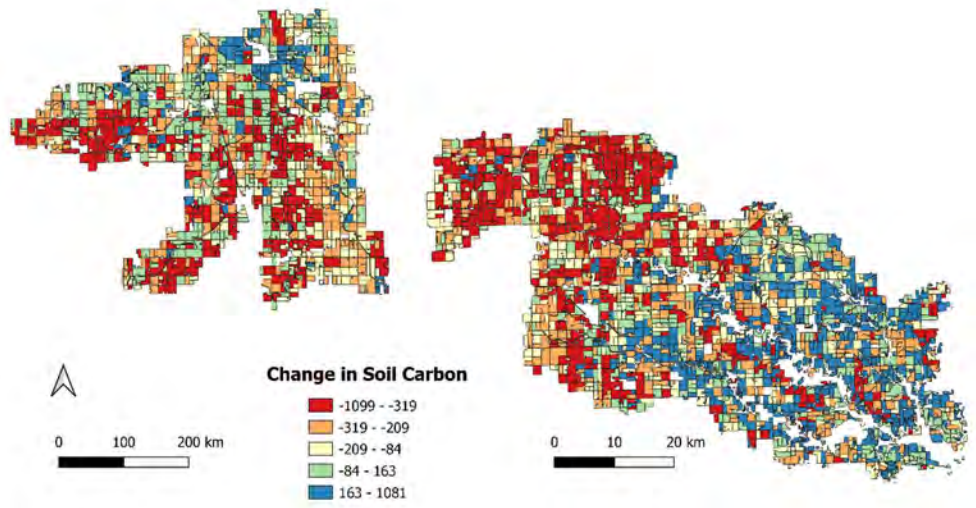

Figure 3. Soil carbon changes (kg/yr of C) associated with the four-year (2013-2016) simulation models when shifting from the conventionally tilled reference to no-till for the North Raccoon Headwaters (left) and South Fork Bend of the Raccoon River (right). Notice that some manured areas (Fig. 1) lose carbon even without some mixing because the topsoil layer becomes carbon saturated while the subsoil loses organic carbon. The rates of change should not be interpreted literally because there is considerable uncertainty, but the patterns do likely reflect the correct areas with potential for carbon gains.

Outlook

This project enabled development of an agile platform to simulate within field-level granularity regarding the impact of management practices designed to improve landscape management. Simulating fields or sub-fields with Cycles employs the same workflow, the difference being the increasing demands on computational time and storage resources. The visualization as a web service does become more challenging when representing subfields because of the higher volume of data transferred through the network. We suggest that the Cycles-based modeling tool will be of most interest for future studies that can integrate data and modeling tools dynamically to represent either higher spatial or temporal resolution. The mapping or spatial yield variability will only improve with time, and so will the availability of in-season information that may be useful for adjusting canopy development and/or yield projections. The challenge of assembling databases and conducting high-resolution simulations is gradually becoming resolved. The next challenges are to visualize outputs in a way that conveys actionable information to stakeholders (e.g., DataBrains™) and to integrate distributed hydrologic modeling and transport of pollutants via mechanistic modeling or emulators into tools useful to estimate ecosystems services in a landscape design framework.

No. 19. Agricultural Producer Engagement

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Background

The Sustainable Landscape Design project made a very strong commitment to working closely with agricultural producers. In addition to collaborating with them for on-farm establishment of perennial grass and CRP plots, the team conducted several listening sessions designed to better understand their values and priorities in land management and to be sure they were included in project decision making and had opportunities to thoroughly discuss and ask questions about the research results. Analysts from Idaho National Laboratory (INL), Oak Ridge National Laboratory (ORNL) and Penn State University (PSU) conducted a series of interviews with producers across Iowa to ensure producer goals were met as the team identified strategies for sustainable increases in biomass production.

Previous studies have been conducted to assess the willingness of farmers to grow bioenergy crops and to understand how their priorities influenced past land use decisions on their fields. This project was different in that the interviews focused on the values and priorities of the producers so that we – as researchers and industry partners – can better address those priorities in the future. Regarding producer priorities, previous studies often divided farmers into two groups: conventional and environmentally- or sustainability-conscious categories. Instead of focusing on differences or trends of the two groups, our producer engagement goal was to understand how to best include and/or incentivize landscape design priorities which are known to vary across regions, communities, and among different groups of people.

Interview Process

Producer engagement interviews were carried out in two phases (Figure 1). The first used open-ended questions about individual priorities, their understanding of sustainability, and their overall field planning process. During the second phase, farmers were asked to quantify how much they value different factors that influence their decisions. Each second phase of interviews was influenced by findings from the first phase and tailored accordingly for each group.

Figure 1. Cyclical stakeholder engagement process with agricultural producers

To fully understand the diversity and differences in perspectives of each group, project members carried out interviews across different parts of Iowa and with different types of producers. Figure 2 illustrates where interviews were carried out. Those who participated in the interviews included: (1) producers who established perennial grasses for conservation (most of them – as part of this Sustainable Landscape Design project); (2) those who harvest perennial crops (i.e., switchgrass or miscanthus) for biomass; and 3) those who harvest corn stover for bioenergy use.

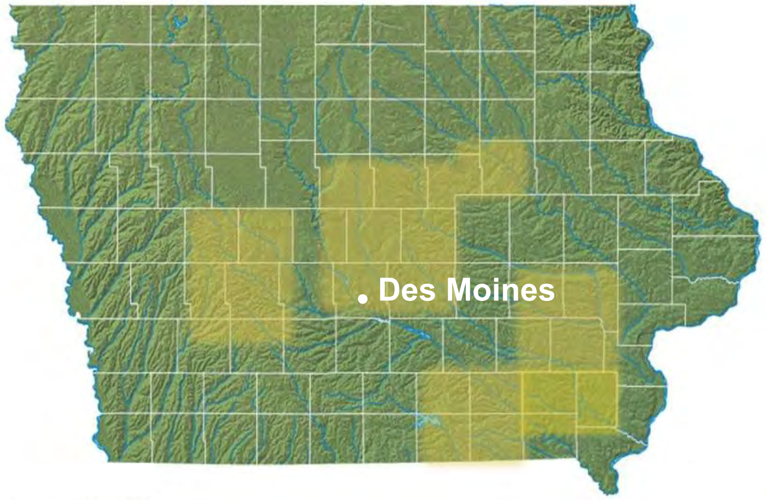

Figure 2. Interview locations across Iowa (marked in yellow)

Phase 1

Thirty-seven (37) interviews were conducted with 46 people across Iowa in February 2019. Producers were asked questions to understand what they value in agriculture and farming and what “progress” or “improvement” in farming practices or agricultural systems means to them. Examples of the questions that were used in the interview process are presented in Box 1.

As a result of the interviews, researchers identified 18 priorities that were consistently mentioned among all agricultural stakeholder groups. The “top” priorities were selected based on the frequency with which specific terms were used in context with the interview questions. As expected, some of the top priorities were profitability, financial stability, erosion control, and water and soil quality. In addition to these commonly modeled factors, the interviews identified other priorities such as independence and positive community image, factors that are less tangible, but can still influence a farmer’s decision to plant a “new” perennial crop. For example, if growing the crop can result in fields that are “messy-looking”, community standing might impact their decision regarding whether or not to plant it.

Box 1. Phase 1 questions (select examples)

- What issues in agriculture are currently most concerning to you?
- What do you value in farming and agriculture? How would you measure that value?
- What is the (up to three) decision you would make to improve the current situation for agriculture?
- What would you measure or monitor to evaluate the improvements that resulted from your actions?
- What [which indicators] would influence your decision around planning and managing your farm? (If you use conservation practices, what motivates you to do so?)

Phase 2

Phase 1 interviews provided an understanding of agricultural producer priorities, but they were rather abstract and difficult to include in decision-making and modeling efforts. Therefore, another set of interviews were conducted during Phase 2. Based on the initial findings, producers were asked to assign weights (the value or relative importance) to the priorities each had previously mentioned. Fifteen interviews with 19 people were carried out across Iowa in November 2019 with a subset of farmers who had been interviewed during Phase 1.

Fifteen priorities were thus identified by farmers for use in their landscape design decisions. Each farmer was asked to place a portion of the poker chips from their limited “fund” to illustrate the priority (shown in Box 2) that would receive most of their resources. The various priorities were printed on cards as illustrated in Figure 3 which shows an example of how one farmer arranged his cards and poker chips.

Box 2. Phase 2 questions (priorities for weighing)

How important is each indicator in the context of all indicators that you found relevant? Please, assign the appropriate number of poker chips and explain why.

Independence
Equal opportunity
Financial stability
Profitability
Yield
Diversification
Water quality
Soil quality
Nature proximity
CO_2 emissions
Erosion potential
Wildlife presence
Food production
Rural development
Positive image
Farming lifestyle
Land inheritability
Young farmers

Figure 3. Farmer assigned how much different priorities mattered to them using poker chips and cards representing those priorities.

Phase 2 interactions with farmers highlighted the need of designing fields specific to each producer's priorities and how those individual priorities varied among every interviewee. Results from those producer interactions were subsequently used by researchers to enhance their simulation modeling efforts. For example, real-life weights from the farmer interviews were assigned when evaluating different landscape layouts. Furthermore, most of the interviews included economic, environmental, and social priorities, thus supporting the need for holistic sustainability assessments when modeling for bioenergy landscapes.

The highly effective, participatory producer interaction associated with this Sustainable Landscape Design project can be used as an example of how to better involve stakeholders in knowledge co-generation at the very beginning of research projects such as this one. A combination of techniques used in Rural Sociology and Ethnography (Phase 1) with those techniques used for Operations Research and group model-building (Phase 2) proved useful and effective for both producers and the research teams. Finally, a very important project/research benefit of the interactions among producers, researchers, and industry personnel, resulted in greater inclusion and a sense of satisfaction among stakeholders in bioenergy feedstock development.

Reference

Vazhnik, Veronika. “Farm Landscape Design Decision Support to Increase Economic, Environmental and Social Benefits Using Stakeholder Engagement, Sustainability Assessment and Spatial Analysis”. Dissertation in BioRenewable Systems for The Pennsylvania State University. May 2020. 230 pages.

No. 20. Soil health and crop yield comparisons among alternative cropping systems in Central Iowa.

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Implementing sustainable agricultural landscape designs to enhance soil health, improve and protect water quality, and provide for continual improvement in operating bioenergy supply systems will require a transition from current Midwest land management practices. During the past 75 years, corn and soybean have displaced oat, hay, and sorghum to become the dominant crops in Iowa, Illinois, and portions of several other states. One objective associated with this project was to quantify soil health and productivity impacts of alternative cropping systems. This Case Study summarizes results from a 25 acre field study conducted at Iowa State University's Agronomy and Ag Engineering Research Center (AAERC) in Boone County, Iowa.

The "Field 70/71" site had been used for a long-term (1975 to 2006) tillage study that was summarized by Karlen et al. (2013a, b). In 2007, the entire site was uniformly tilled by ripping at a depth of ~14 inches and then disk-harrowing before planting an oat crop. This prepared the site for an ARS Renewable Energy Assessment Project (REAP) / Sun Grant Regional Partnership study, funded in part by the DOE, designed to acquire field validation data for the Billion Ton Report (Perlack et al., 2005). Continuous corn using conventional or no-till practices (Table 1)

Table 1. Treatments imposed to provide field validation data for the Billion Ton Report.

Tmt.	Management	Agronomics	Tillage	% Removal
1	Continuous Corn (CC)	32K, 30" rows	Chisel plow	0
2	Continuous Corn (CC)	32K, 30" rows	No-till	0
3	Continuous Corn (CC)	32K, 30" rows	Chisel plow	50
4	Continuous Corn (CC)	32K, 30" rows	No-till	50
5	Continuous Corn (CC)	32K, 30" rows	Chisel plow	100
6	Continuous Corn (CC)	32K, 30" rows	No-till	100
7	High Input Continuous Corn (CC)	45K, twin-rows	Chisel plow	0
8	High Input Continuous Corn (CC)	45K, twin-rows	No-till	0
9	High Input Continuous Corn (CC)	45K, twin-rows	Chisel plow	50
10	High Input Continuous Corn (CC)	45K, twin-rows	No-till	50
11	High Input Continuous Corn (CC)	45K, twin-rows	Chisel plow	100
12	High Input Continuous Corn (CC)	45K, twin-rows	No-till	100
13	CC + 4 t/ac biochar	32K, 30" rows	Chisel plow	0
14	CC + 8 t/ac biochar	32K, 30" rows	Chisel plow	0
15	CC + 4 t/ac biochar	32K, 30" rows	Chisel plow	50
16	CC + 8 t/ac biochar	32K, 30" rows	Chisel plow	50
17	CC + 4 t/ac biochar	32K, 30" rows	Chisel plow	100
18	CC + 8 t/ac biochar	32K, 30" rows	Chisel plow	100
19	CC + Annual rye cover crop	32K, 30" rows	No-till	50
20	CC + Annual rye cover crop	32K, 30" rows	No-till	100
21	CC + White clover cover crop	32K, 30" rows	No-till	50
22	CC + White clover cover crop	32K, 30" rows	No-till	100

was grown for the first four years. Row spacing was decreased from 36 to 30 inches to create 22 0.27 acre??? plots in each of four replicates. Biochar and annual and perennial cover crop treatments were also included. Stover harvest rates were nominally referred to as 0, 50, and 100% with actual removal being none, moderate (25 to 35%) or high (~70%) amounts of above-ground biomass as noted by Obrycki et al. (2018a, b) in their soil health and productivity reports.

As the landscape design project moved forward, the cropping system treatments were slowly transitioned to include: (1) annual cover crops that were harvested as an additional cellulosic biomass source prior to planting soybean (Case Study No. 9); (2) alfalfa as part of a five-year (alfalfa-alfalfa-alfalfa-corn-corn) rotation; and (3) a diversified rotation that included corn, rye, soybean, wheat, and a mixed cover crop (oats, peas, and tillage radish) as shown in Table 2.

Table 2. Landscape design cropping system treatments evaluated for 2015 through 2020.

Tmt.	Cropping System	Tillage	% Stover Harvest
1	Continuous Corn (CC)	Chisel plow	0
2	Alfalfa, Alfalfa, Corn, Corn, Alfalfa, Alfalfa	No-till	100
3	Continuous Corn (CC)	Chisel plow	50
4	Continuous Corn (CC)	No-till	50
5	Continuous Corn (CC)	Chisel plow	100
6	Continuous Corn (CC)	No-till	100
7	Corn, Alfalfa, Alfalfa, Alfalfa, Corn, Corn	No-till	100
8	Alfalfa, Alfalfa, Alfalfa, Corn, Corn, Alfalfa	No-till	100
9	Alfalfa, Corn, Corn, Alfalfa, Alfalfa, Alfalfa	No-till	100
10	Rye/Soy, Wheat/radish-legume, Corn/rye, Rye/Soy, Wheat/radish-legume, Corn/rye	No-till	50
11	Corn, Corn, Alfalfa, Alfalfa, Alfalfa, Corn	No-till	100
12	Corn/rye, Rye/Soy, Wheat/radish-legume, Corn/rye, Rye/Soy, Wheat/radish-legume	No-till	100
13	Continuous Corn (CC) + 4 t/ac biochar	Chisel plow	0
14	Continuous Corn (CC) + 13 t/ac biochar	Chisel plow	0
15	Continuous Corn (CC) + 4 t/ac biochar	Chisel plow	50
16	Continuous Corn (CC) + 13 t/ac biochar	Chisel plow	50
17	Continuous Corn (CC) +4 t/ac biochar	Chisel plow	100
18	Continuous Corn (CC) + 13 t/ac biochar	Chisel plow	100
19	Corn/rye, Rye/Soy, Wheat/radish-legume, Corn/rye, Rye/Soy, Wheat/radish-legume	No-till	50
20	Wheat/radish-legume, Corn/rye, Rye/Soy, Wheat/radish-legume, Corn/rye, Rye/Soy	No-till	100
21	Wheat/radish-legume, Corn/rye, Rye/Soy, Wheat/radish-legume, Corn/rye, Rye/Soy	No-till	50
22	Rye/Soy, Wheat/radish-legume, Corn/rye, Rye/Soy, Wheat/radish-legume, Corn/rye	No-till	100

Figure 1 and Table 3 show that with appropriate management, no-till production (especially with partial stover harvest) can be successful and economically viable (Obrycki et al., 2018b)

Figure 1. Corn grain and stover yield response to tillage at a Boone County Iowa site.

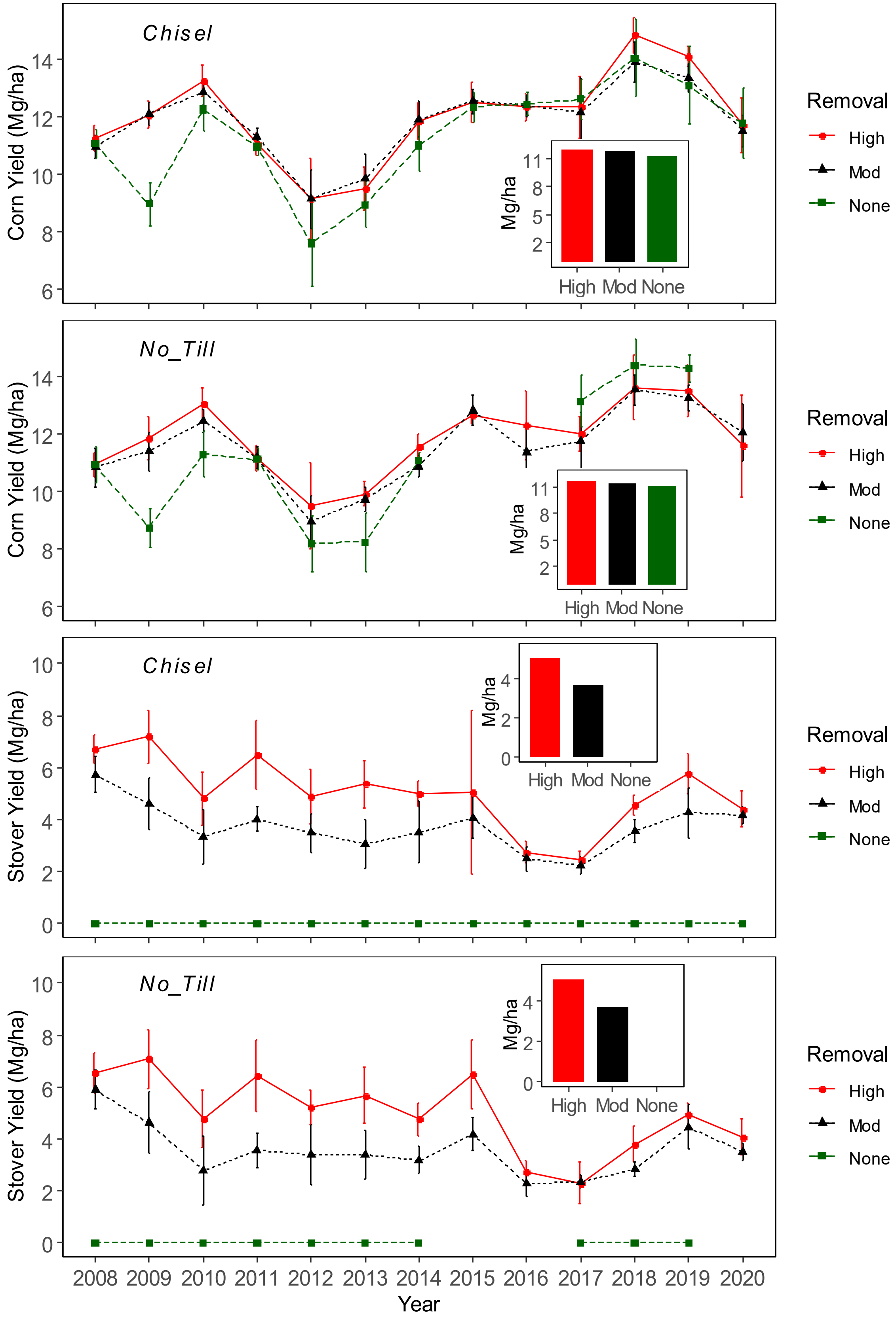

Table 3. Average stover and grain yields for the tillage and removal rate treatments.

Tillage	Removal	Corn	Stover
		Mg ha^{-1}	
No-till	High	11.7	5.14
	Mod	11.4	3.68
	None	10.9	0
Mean		*11.7*	*3.72*
Chisel	High	11.9	5.08
	Mod	11.8	3.73
	None	11.3	0
Mean		*11.4*	*2.94*
Removal	High	11.8	5.10
	Mod	11.6	3.71
	None	11.2	0

Stover harvest (none, moderate, high), tillage [chisel (CP) vs no-till (NT)], crop rotation [(continuous corn (CC) corn-alfalfa (CA) or diversified (D)], and biochar (0, 4, or 13 t/ac) effect on soil organic C (SOC) concentrations and soil health index (SQI) scores within the 0- to 5- and 5- to 15-cm depth increments were also quantified and are presented in Figure 2.

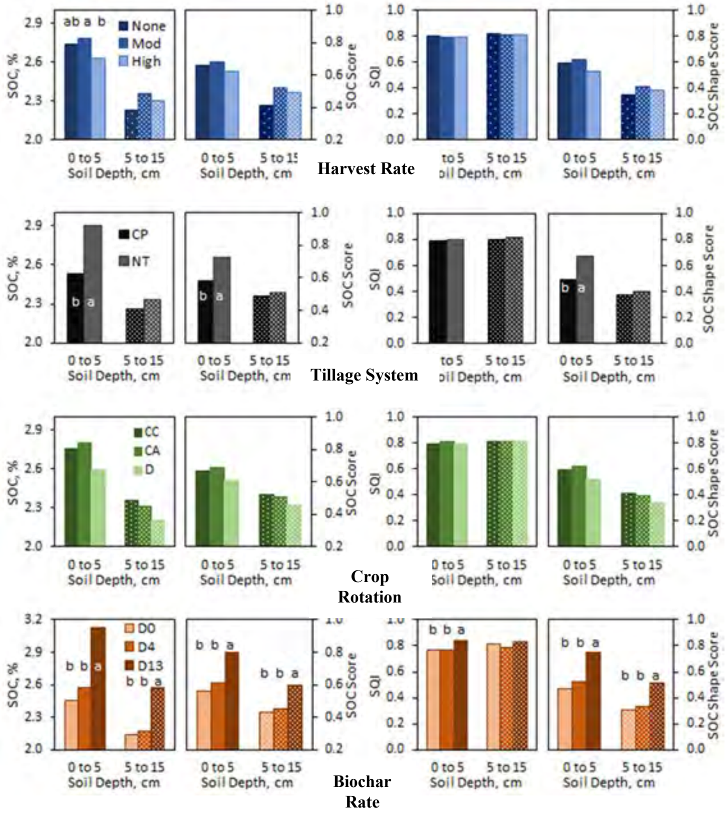

Figure 2. Corn stover harvest, tillage, crop rotation and biochar effects on SOC concentration, score, and SQI indices for 0- to 5- and 5- to 15-cm depth increments.

The variation in SOC concentrations, SMAF [Soil Management Assessment Framework (Andrews et al., 2004)] and SHAPE [Soil Health Assessment Protocol and Evaluation tool (Nunes et al., 2021)] scores for SOC and an overall SMAF index value (SQI) for all 22 treatments are shown in Figure 3. Averaging across all treatments, shows that mean SOC values were significantly ($p<0.05$) higher with no-till than with chisel plow management (Figure 2). Incorporating alfalfa into the rotation and continuing to use no-till practices for corn resulted in a slightly higher SOC concentration within the surface 5 cm. Diversifying the no-till crop rotation to include wheat and a cover crop mixture with "tillage radish" was intended to further increase SOC, but no significant differences could be detected among the diversified (D), continuous corn (CC) and corn-alfalfa (CA) rotations. This presumably reflected the short amount of time those treatments were implemented and may have also been influenced by biochar applications to some of the CC treatments (Table 2). Focusing specifically on average SOC values for biochar treatments, the high rate (13 Mg ha^{-1}) resulted in a higher mean concentration than either the low (4 Mg ha^{-1}) or zero application rate (Figure 2) within both depth increments.

The SMAF index value (SQI) was computed to assess overall soil health response to landscape designs that included different tillage practices, biochar application rates, crop rotations, and stover harvest rates. Five indicator measurements (SOC, bulk density, pH in water, Bray-P, and Exch. K) were used as input data. There was no significant difference among treatments with all SQI values averaging approximately 0.8 (80%). This indicates the soil was functioning well for all cropping systems and stover harvest rates (Figure 3), although there was room for improvement. The two indicators most responsible for decreasing SQI values from an ideal 1.0 value were SOC and pH. The SOC concentrations had been reduced by farming compared to those associated with pristine tall-grass prairie across the entire site and for some treatments pH scores were below those considered ideal for corn.

The SMAF and SHAPE SOC scores both ranged from 0.49 to 0.80 and mimicked SOC lab measurements. For both indices, the highest scores were observed for the no-till, corn-alfalfa rotation, and high biochar treatments (Figure 3). SOC scores were also higher within the top 5 cm than within the 5 to 15-cm depth increment, especially within the no-till treatments.

Overall, the effect of stover harvest on soil health was minimal and generally not significant (data not presented). This suggests that the adoption of conservative agricultural practices such as reduced tillage, cropping system diversification, and addition of biochar can prevent potential negative effects of harvesting corn stover on overall soil health. The positive no-till response indicates that crop roots left in soil are more important than the above-ground crop residue for maintaining or increasing SOC and soil health. This is consistent with results from a recent publication by Nunes et al. (2021).

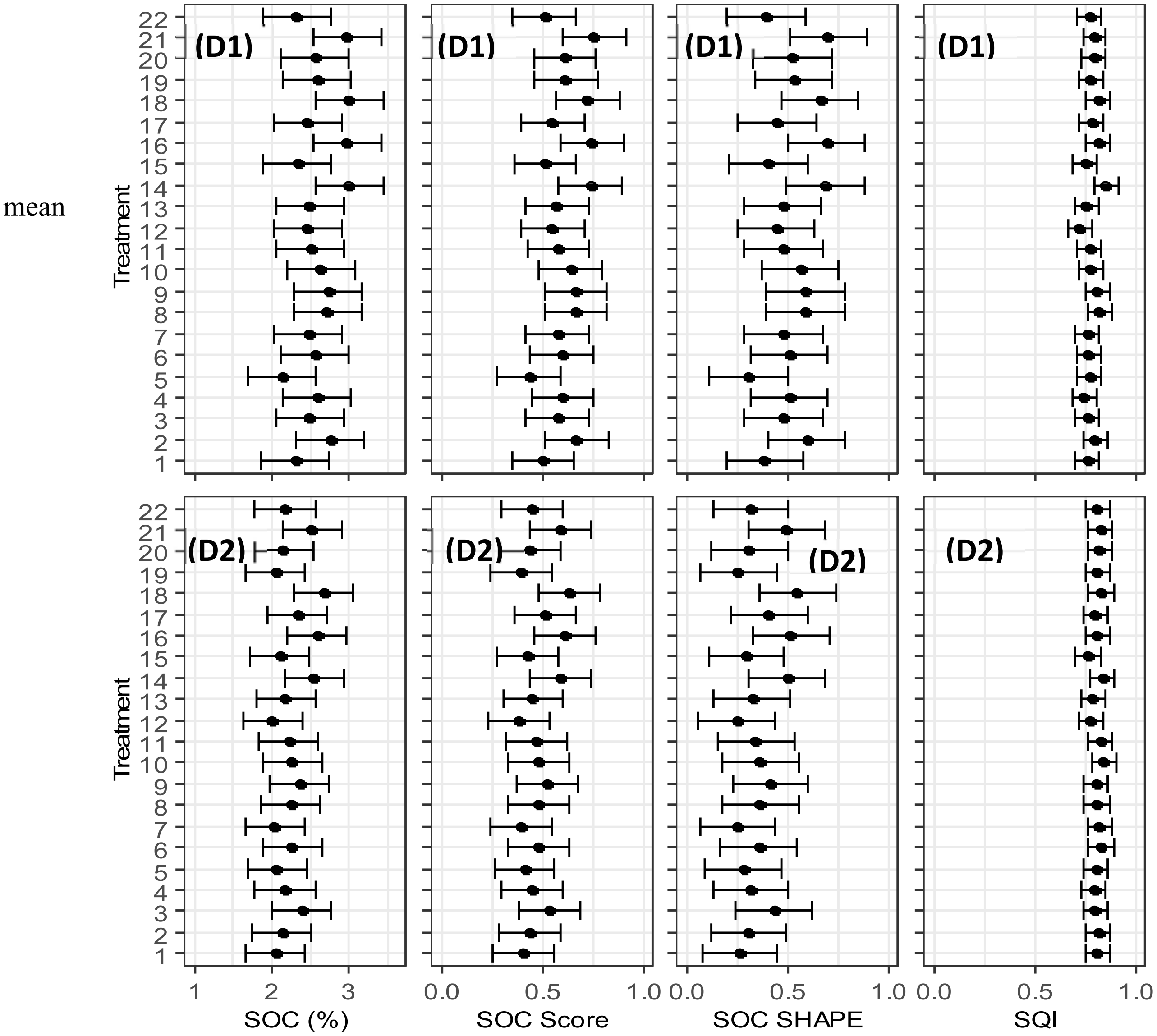

Figure 3. Treatment variation in (i) SOC concentrations, (ii) SOC scores using SMAF or SHAPE, and (iii) SQI values within the 0 to 5- and 5 to 15-cm depth increments.

The major soil health benefit associated with roots remaining in the ground, regardless of aboveground biomass management, is a key component of landscape design. Root C has a higher potential to be stabilized in soil and thus can have a longer residence time than shoot C. This is reflected by the SMAF and SHAPE scores (Figure 4). SHAPE, which is being developed as an improved assessment tool compared to the SMAF, is more dynamic and accounts for the full range of SOC values for a specific soil group under specific climate conditions. Herein, the SHAPE scores indicate that for the taxonomy, texture, mean annual temperature (MAT), and annual precipitation (MAP), SOC concentrations are nearly at their highest potential levels for some treatments, including chisel plowing with the addition of biochar.

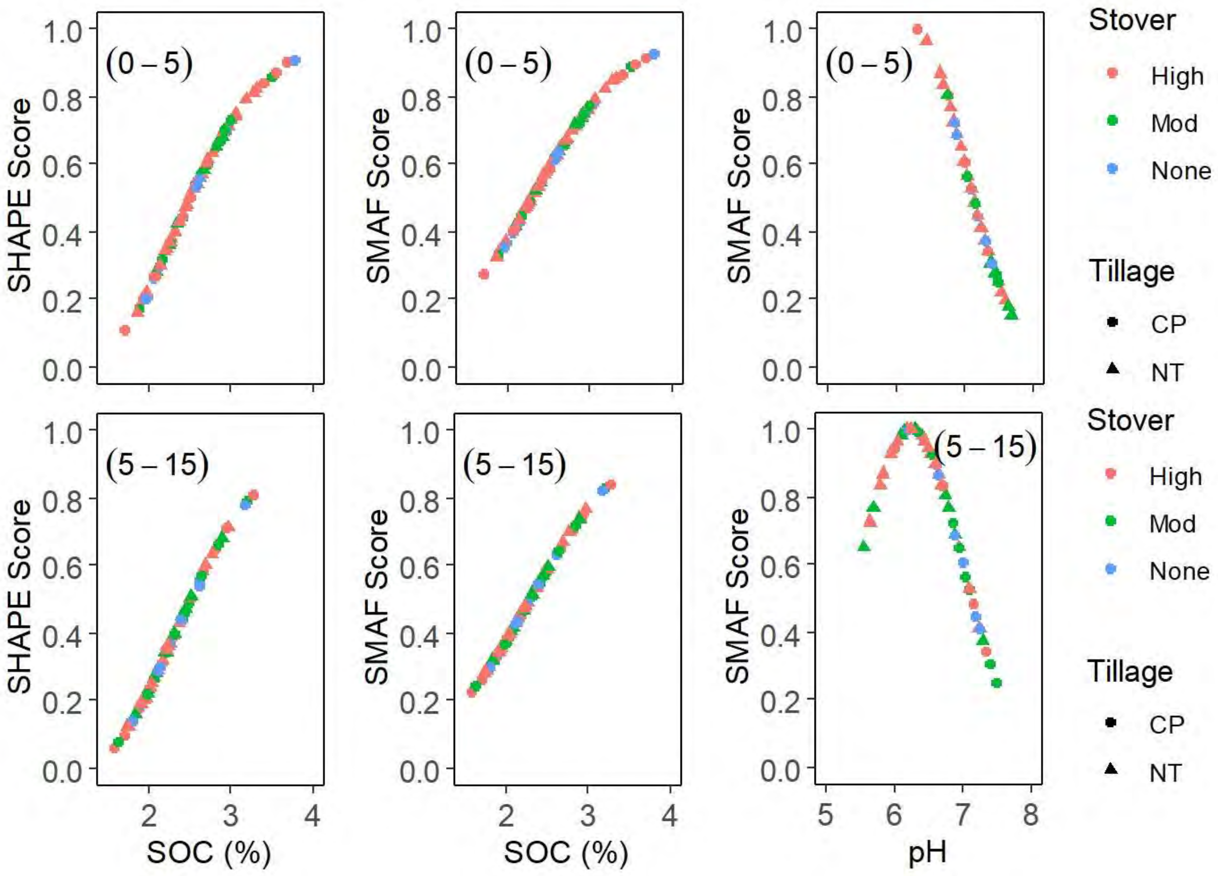

Figure 4. SHAPE and SMAF scores for SOC and soil pH within the 0- to 5- and 5- to 15-cm depths.

References

Andrews, S.S., Karlen, D.L., Cambardella C.A. (2004). The Soil Management Assessment Framework: a quantitative soil quality evaluation method. Soil Sci. Soc. Am. J., 68, 1945-1962

Karlen, D. L., Cambardella, C. A., Kovar, J. L. and Colvin, T. S. 2013b. Soil quality response to long-term tillage and crop rotation practices. Soil & Tillage Research. 133:54-64.

Karlen, D. L., Kovar, J. L., Cambardella, C. A. and Colvin, T. S. 2013a. Thirty-year tillage effects on crop yield and soil fertility indicators. Soil & Tillage Research. 130:24-41.

Nunes, M. R., De, M., McDaniel M., Kovar, J., Birrell, S., Karlen, D. L. 2021. Science-based maize stover removal can be sustainable. Agronomy Journal. https://doi.org/10.1002/agj2.20724.

Nunes, M. R., Veum, K. S., Parker, P. A., Holan, S. H., Karlen, D. L., Amsili, J. P., van Es, H. M., Wills, S. A., Seybold, C. A., Moorman, T. B. 2021. The Soil Health Assessment Protocol and Evaluation Applied to Soil Organic C. Soil Science Society of America Journal. https://doi.org/10.1002/saj2.20244

Obrycki, J. F., Karlen, D. L., Cambardella, C. A., Kovar, J. L., and Birrell, S. J. 2018a. Corn stover harvest, tillage, and cover crop effects on soil health indicators. Soil Science Society of America Journal 82:910-918. https://doi:10.2136/sssaj2017.12.0415

Obrycki, J. F., Kovar, J. L., Karlen, D. L., and Birrell, S. J. 2018b. Ten-year assessment encourages no-till for corn grain and stover harvest. Agricultural & Environmental Letters. 3:180034. https://doi:10.2134/ael2018.06.0034

Perlack, R. D., Wright, L. L., Turhollow, A. F., Graham, R. L., Stokes, B. J., and Erbach, D. C. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply DOE/GO-102005-2135 and ORNL/TM-2005/66. https://www1.eere.energy.gov/bioenergy/pdfs/final_billionton_vision_report2.pdf

Rogovska, N., Laird, D. A., and Karlen, D. L. 2016. Corn and soil response to biochar application and stover harvest. Field Crops Research. 187:96-106.

No. 21. Effects of Management History on Root Characteristics and Soil Health

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Background

Soil health is a major concern for farmers; however there remains some uncertainty surrounding which crop management practices most efficiently optimize soil health, as well as how these crop management practices influence soil health in both time and space. Management regimes which promote year-round soil cover and biodiversity in the root zone are thought to promote soil health by mitigating soil erosion (Wilhelm et al. 2010), increasing soil organic carbon (Moore et al. 2014, Moore 2021), and augmenting soil biological activity (McDaniel et al. 2014). Landscape position, including percent slope, is also thought to play a role in soil health variability (Kaspar et al. 2006). Roots also contribute to soil properties and processes (i.e., health) as both dead plant tissue (residue) and while growing through intentional and/or unintentional release of carbon-compounds at an estimated rate of 800 to 4500 kg C ha^{-1} yr^{-1} (McDaniel et al., 2014). These observations support the idea that: 1) Conservation Reserve Program (CRP) and pasture root activity contribute greater soil health benefits than corn roots due to greater diversity of root traits, 2) root carbon-to-nitrogen ratio and physical characteristics contribute more to soil health than total root biomass, and 3) low-slope landscape positions show greater improvements to soil health compared to high-slope landscape positions.

A comprehensive landscape study spanning multiple sites in Iowa and incorporating different crop management practices was designed to test the validity of these hypotheses. Farm sites were located throughout central Iowa, including locations in Guthrie Center, Newton, and Panora. The crop management practices we examined were corn/soybean (row-crop), grazed (pasture), and conservation reserve program areas that had been in place for 30 years or more (CRP). Our goal was to relate soil health indicators to plant root characteristics at both high- (13 to 25%) and moderate-slope (7 to 13%) landscape positions.

Our two main objectives were to determine: (1) effects of management history and landscape position on root characteristics, and (2) how root characteristics are related soil health.

Soil and Plant Root Collection

Samples were collected during fall 2018 and 2019. Soil cores and root samples were taken at each location in fields managed with each of the main crop management practices (i.e., corn/soybean, pasture, and CRP) in both high-slope and low-slope landscape positions after all crop and prairie plots were harvested. A hydraulic Giddings™ soil probe was used to collect soil cores to a depth of 1.2 m. Samples were divided into six depth increments: 0 to 5-, 5 to 15-, 15 to 30-, 30 to 60-, 60 to 90-, and 90 to 120-cm.

Soil Analysis

Samples were analyzed for a range of biological, chemical, and physical properties: organic matter, mineralizable carbon, permanganate oxidizable carbon, and beta-glucosidase (Biological indicators); N, P, K, S, Mg, Mn, Fe, cation exchange capacity, and pH (Chemical indicators); and aggregate weight, texture, and bulk density (Physical indicators). These soil health indicators were compared to root characteristic data taken from adjacent field sites identified using precision GPS to match the sampling locations to within 10 cm. For additional soil health results and discussion, please see Case Study No. 10.

Root Analysis

Plant root tissue was separated from soil particles using a root washing system (Video 1). The process included soaking the soil samples in a dispersing agent that was then mixed into a slurry. The slurry was placed into the root washing system, or elutriator, which separated plant roots from the soil matrix (Flowchart 1).

Recovered root tissue was placed on a flatbed scanner and scanned to create high-resolution images. These images were then entered into root scanning software (RhizoVision©). The software quantified various root characteristics, including total root length, branching frequency, root area, and mean diameter.

Video 1. The elutriation device used to separate root biomass from soil (https://iastate.box.com/s/qgqnj7823r47v0ng7dhnema5kyd4gp8c)

Preliminary Observations

Plant root biomass stocks (Mg ha^{-1}) by depth and land use are shown in Figure 1.

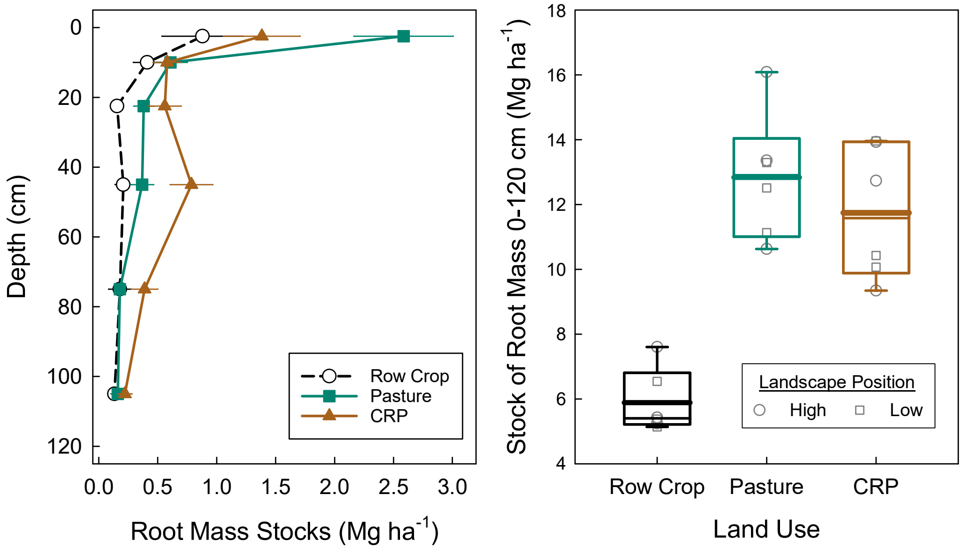

Figure 1. Root biomass stocks by depth (left) and total stocks to 120 cm depth (right). Pasture increases root biomass by 86% and 194% at 0-5 cm depth compared to CRP and Row Crops, but CRP has greater 56% to 93% greater root mass across 20-80 cm depths compared to Pasture and Row Crop. When summing roots across all depths, both Pasture and CRP nearly double root mass compared to Row Crop.

Multimedia Presentation

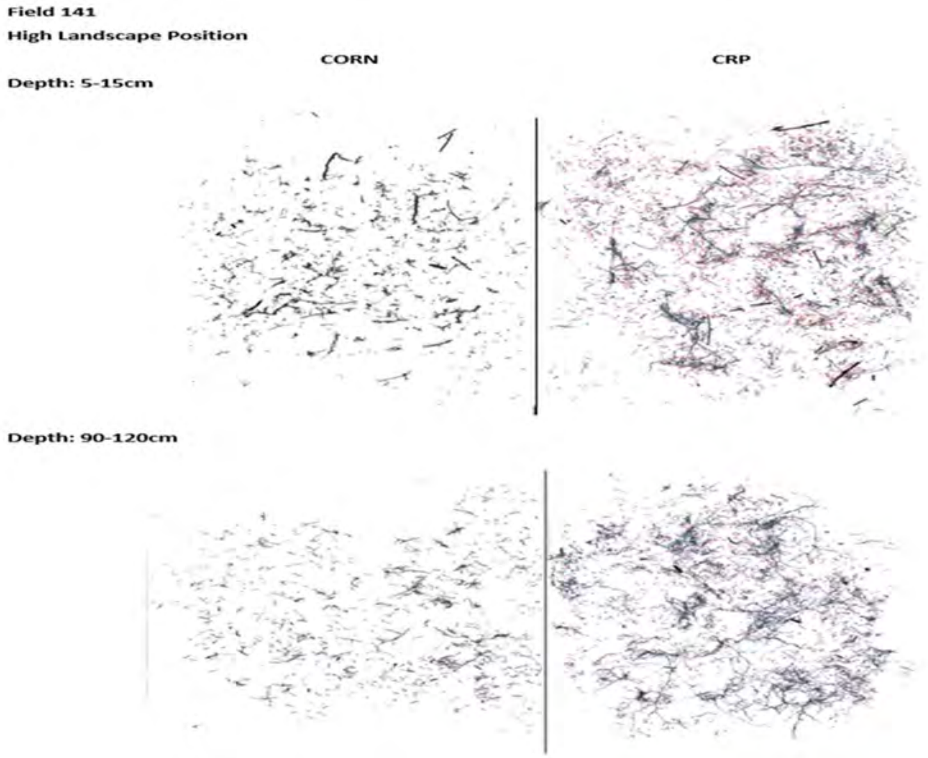

Image Set 1. An example of root characteristic differences between corn and CRP at two depth intervals (top row: 5-15cm, bottom row: 90-120cm) in a highly sloped landscape position.

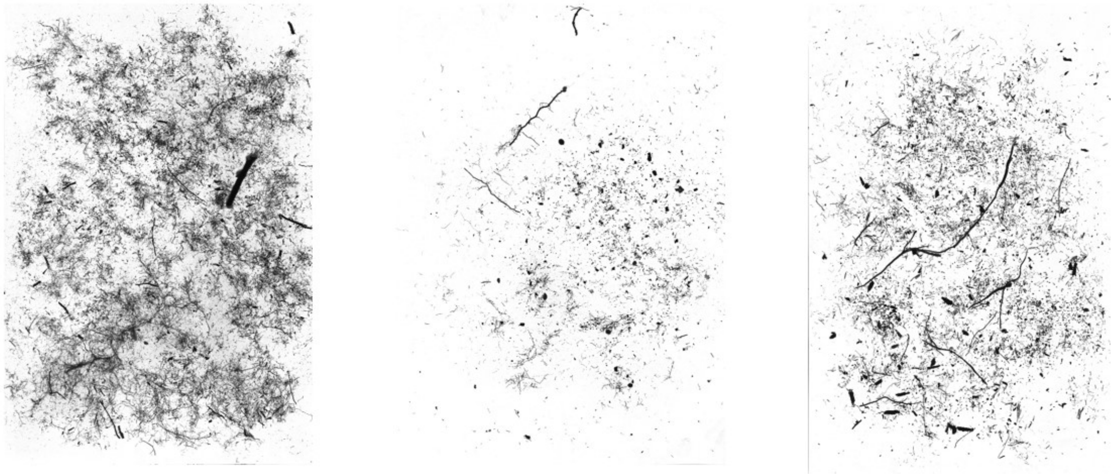
Pasture 5-15cm depth
30 Yr. CRP 5-15cm depth
Corn/Soy 5-15cm depth

Image Set 2. An example of root characteristic differences typical of the main crop management effects (pasture, CRP, and corn-soybean rotation) in the 5-15cm soil layer.

Flowchart 1. A pictorial summary of the plant root extraction process.

References:

Kaspar, T. C., T. B. Parkin, D. B. Jaynes, C. A. Cambardella, D. W. Meek, and Y. S. Jung. 2006. Examining changes in soil organic carbon with oat and rye cover crops using terrain covariates. Soil Sci. Soc. Am. J. 70:1168-1177.

Neumann, G. (2007). Root exudates and nutrient cycling. In Nutrient cycling in terrestrial ecosystems (pp. 123-157). Springer, Berlin, Heidelberg.

McDaniel, M. D., L. K. Tiemann, and A. S. Grandy. 2014. Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis. Ecological Applications 24:560-570.

Moore, E. B. 2021. Management effects on near-surface soil properties in a temperate corn-soybean cropping system. Graduate Theses and Dissertations 18564. https://lib.dr.iastate.edu/etd/18564

Moore, E. B., T. C. Kaspar, M. H. Wiedenhoeft, and C. A. Cambardella. 2014. Rye cover crop effects on soil properties in no-till corn-silage-soybean cropping systems. Soil Sci. Soc. Am. J. 78:968-976.

Wilhelm, W. W., J. R. Hess, D. L. Karlen, J. M. F. Johnson, D. J. Muth, J. M. Baker, H. T. Gollany, J. M. Novak, D. E. Stott, and G. E. Varvel. 2010. Balancing limiting factors and economic drivers for sustainable Midwestern US agricultural residue feedstock supplies. Industrial Biotechnology 6:271-286.

No. 22. Landscape Design Principles Associated with Soil Carbon Management Dynamics

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The landscape design concept as addressed in this multi-agency research and technology transfer project focused on balancing economic, environmental, social components agriculture. Project activities included: (1) developing tools to identify non-profitable agricultural areas with high environmental impact for conversion from row- to perennial-crop production, (2) coordinating various conservation programs (e.g., CRP) to make the conversions economically viable, and (3) quantifying soil health, water quality, ecosystem service, producer and stakeholder response, while also striving to provide increased amounts of reliable and sustainable cellulosic feedstock supplies for bioenergy or other bio-products. During the five-year period this project was being conducted (2017 through 2021), public recognition of the importance of increasing soil organic carbon (SOC) stocks as a mitigation strategy for addressing climate change and reducing greenhouse gas (GHG) levels increased exponentially. This Case Study discusses how landscape design principles can affect the dynamics of SOC management. Our perspective is that SOC management dynamics are not only affected by diversified landscape management strategies, but also are critical factor for every land use decision or environmental policy proposal.

SOC is a very important indicator of natural resource sustainability because of the multiple soil properties and processes it influences. Total SOC reflects dynamic changes associated with C moving into and out the soil rapidly through the carbon cycle. These changes are sometimes referred to as biogenic C because, in contrast to fossil C, it is from recent biological activity. Ideally, biogenic C inputs over time will sufficiently exceed SOC output and thus result in an increase in sequestered C that will remain in soil for decades to more than 100s of years. Understanding C cycling and stored C processes were both addressed in multiple ways in the design and implementation of this landscape design project. SOC was monitored or modelled for its effects on productivity and profitability; response to tillage, crop rotation, or land use practices; and impact on carbon sequestration, retention, and storage. Case Studies 2, 7, 8, 9, 10 18 and 21 document potential SOC impacts of several landscape design components.

Case Study 2 identified SOC as one of 15 potential sustainability indicators within the Field Landscape Decision Support (FieLDS) decision tool. The authors discuss the importance of SOC and how the FieLDS tool can be used to assist agricultural producers and farm managers in selecting the most appropriate field segments for conversion from commodity crops to perennial cellulose feedstock sources. Connections between SOC and the multiple producer and stakeholder needs and priorities, including increased profitability, provision of reliable feedstock supplies, and enhancing ecosystem services are an integral part of that Case Study. The importance of SOC as an indicator for assessing sustainability of alternative landscape designs was discussed in Case Study 7; its critical role for guiding sustainable corn stover harvest was discussed in Case Study 8; and the effects of using cover crops to potentially increase SOC while diversifying agricultural landscapes was discussed in Case Study 9. In Case Study 10, SOC was one of eight soil health indicator measurements used to create a minimum Soil Management

Assessment Framework (SMAF) data set for assessing effects of various landscape design practices including enrollment in Conservation Reserve Programs (CRP) or planting long-term pasture or bioenergy feedstock grasses. The SMAF provides an operational link between landscape design and soil health improvement practices. Finally, the role of SOC in the Cycles simulation model was discussed in Case Study 18. Cycles is a user-friendly, multi-crop, multi-year, process-based agroecosystems model with daily time step simulations of crop production and the water, carbon (C) and nitrogen (N) cycles in the soil-plant-atmosphere continuum.

Soil properties, processes, management

We suggest the most important SOC management principle is an understanding of how SOC is affected by various soil properties, processes, and management properties/processes interact in response to various short-term weather and long-term climate drivers. This SOC management principle is crucial because from a soil resource perspective, every property and process will be affected by the landscape design strategies implemented to enhance the sustainability of cellulosic feedstock production. Concurrent with research and technology transfer activities supporting this Landscape Project, several members of the team contributed to a pair of books that provide insight and references for understanding and measuring soil health (Karlen et al., 2021a, b). Key principles, practices affecting, and methods for assessing SOC addressed in those books are summarized below.

First, it is important to recognize that soil resources are inherently different and must be managed using site-specific practices. Any broad generalizations used for data interpretation or projections with experiential or computer simulation models, no matter how good, will encounter difficulties when being implemented. It may be trite, but fundamentally, “all models are wrong – some however are very useful”, for understanding processes, exploring potential outcomes, and/or predicting SOC response to soil and crop management practices.

A second point is that soil health encompasses soil biological, chemical, and physical properties and processes, many of which are directly or indirectly related to SOC. Management practices in the context of this Landscape Design project include corn stover or other crop residue harvest strategies, conversion to perennial crops including switchgrass, miscanthus, woody species and transition of highly erodible, low-productivity cropland into a conservation program. These management strategies can all be incorporated into appropriate landscape design strategies depending first and foremost on the site-specific conditions including the basic soil forming factors and prevailing climatic and weather conditions. Therefore, monitoring soil health properties can be an effective strategy for assessing soil management practices effects on SOC dynamics and stocks.

Directly monitoring SOC concentrations and stocks is commonly done because of the close relationships between SOC and several soil health indicators. Interpretations of SOC dynamics, however, must recognize that changes in SOC stock generally occur very slowly. Also, when monitoring SOC response to management it is essential to measure to a depth of at least 60 cm, with depths of 100 cm or more being highly desirable to account for redistribution of carbon related to tillage or by plant roots. Reports of dramatic changes in SOC stocks need to be viewed with caution, as it may be an artifact of sampling (i.e., excessive inclusion of plant materials), large input of manure or compost, or other sampling and/or analytical differences. Unexpected or unusual SOC change might also be caused by inclusion of ephemeral forms of C that ultimately cycle back into the atmosphere. Rapid assessment of trends that are likely to significantly influence shifts in long-term SOC stocks include indicators such as active carbon. These are well-documented in soil health literature (e.g., Karlen et al., 2021a, b) but are beyond the scope of this Case Study.

A third principle is that when monitoring SOC response to management is that it is critical to also measure bulk density. This is essential so that SOC stock (mass per unit area) and not just concentration (mass per unit mass) can be calculated. Management practices, especially shifts in tillage can change the volume of soil causing shifts in concentration unrelated to the actual amount of SOC stored within the soil profile. Detailed and comprehensive literature exists regarding methods for collecting and processing soil for measuring SOC and bulk density so herein we only highlight a few points for consideration.

Collecting soil cores is the most accurate and efficient method albeit labor-intensive. Several types of probes for soil core collection are available such as hand probes, foot-assist, slide and hammer, and hydraulically driven probes. In all cases, the inner diameter needs to be measured so the sample volume can be calculated. Since determining bulk density requires drying the soil at a high temperature that also alters SOC and other nutrient concentrations so a separate, corresponding core must also be collected. Each soil core should be divided into increments of the desired fixed depth increment (X cm), fixed mass (accounts for compaction) or soil horizon information. The choice of depth increment is based on the overall SOC quantities that are being presented and evaluated.

Other methods estimating bulk density such as those based on remote or spectral sensing typically need to be interpreted with moisture and clay content. Bulk density estimates based on those measurements provide information on inherent BD (i.e., based on the soil forming factors) but not on dynamic BD which reflects management [i.e., cropping system (annuals vs perennials), wheel traffic compaction, animal compaction, residue harvest or tillage. Likewise, estimating bulk density using penetrometer resistance, torque, or similar techniques may be useful and those techniques are in an experimental stage. However, they too must be corrected based on soil water content. Resistance measurements can also provide useful information related to the soil environment as encountered by plant roots but are not advised for monitoring changes in SOC stocks.

Considerations related to monitoring SOC dynamics and stock must also include sampling and handling techniques, drying temperatures, removal of non-soil materials (e.g., rock fragments and roots), grinding, homogenization and subsampling. The relative importance of these factors is strongly affected by the analytical method. For long-term SOC stock quantification, non-soil materials such as pebbles and plants parts must be removed to avoid over-estimation of SOC. Furthermore, the soil should be tested for presence of inorganic carbonates (e.g., calcium or magnesium carbonates). When a soil pH is near or above neutral (pH 7), then inorganic carbonates are likely and should be removed or measured.

The Walkley-Black measurements of SOC uses chromium or other heavy metals, which are considered environmental risks. The method also requires multipliers for interpretation. Therefore, this method has been largely discontinued by the soil science community in favor of high-temperature combustion methods. Those methods are designed to detect C and report the total C concentration within the combusted sample.

Many commercial soil-testing laboratories use Loss on ignition (LOI) which measures the change in sample mass and report that change as soil organic matter (SOM). The mass of C then needs to be estimated using a conversion factor that assumes SOM is about 56% C, but in reality, actual C concentrations may differ and increase the variability and potential error if used to quantify SOC stock. Commercial labs generally use their SOM estimates for soil fertility assessments and fertilizer recommendations, their soil sampling is generally limited to the surface 15 to 30 cm, and they generally do not have accompanying bulk density data. As result the LOI method may be useful for relative comparisons, but it is not recommended when more accurate determinations are needed for assessing changing SOC stock.

Soil erosion is another major factor that decreases soil health in many ways including direct loss, decreased storage volume and altered SOC dynamics. Case Study No. 6 focused on the erosion component of our Landscape Design project. Excessive cellulosic feedstock harvest can result in inadequate soil surface cover, thus exposing the resource to the erosive forces of wind and water. Also, the force of gravity during tillage can result in soil moving downslope, a process referred to as ‘tillage erosion’.

Removal of crop residues can alter soil aggregate size distribution, increasing the preponderance of small aggregates that are more likely to erode. It has been well-documented that over-zealous stover harvest causes an increase soil erosion AND depletes SOC stocks. Production of perennial cellulosic feedstocks offers an opportunity to slow erosion, but until full establishment of switchgrass and Miscanthus stands, soil beneath those crops can also be at risk for water erosion. In semi-arid regions where wind erosion can be problematic, a stubble height of 30 cm or more is recommended. Finally, although, not addressed in this project, soil that is displaced during erosion can be at higher risk for SOC loss. Erosion selectively causes loss of the SOC rich surface horizons and expose sub-surface horizons that are frequently less productive and have degraded soil health characteristics.

Soil compaction interacts with SOC directly and indirectly. Soil compaction can be quantified by bulk density and penetrometers resistance, but neither of these measurements fully capture properties of compacted verses an uncompacted soil. High-axle loads can compact soil deep into the profile and once compacted that soil physical state can persist for many years. Reflecting on this Landscape Design study, harvesting feedstock probably presents the greatest risk for causing soil compaction. This is especially true if sub-optimal weather forces prevail during harvest, thus causing the soil to be more vulnerable to compaction forces (i.e., wet and less stable). Soil compaction can be minimized by using equipment with GPS to make the long-proposed strategy of controlling traffic within designated areas more feasible. This is important because soil compaction can inhibit water drainage, reduce porosity, increase the potential for anerobic conditions, and restrict root growth. Reducing the plant growth and productivity also decreases the amount of annual carbon input for sustaining SOC. The degradation spiral then continues with increases in soil bulk density and a reduction in the soil's ability to withstand the stress caused by wheel traffic.

Nutrient balance can be impacted by harvesting corn stover or other cellulosic feedstocks. In general, unless unmonitored this should not be a problem or alter SOC, but without routine testing, soil fertility will likely decrease, impacting yield and overall system productivity. Regarding corn stover harvest, nitrogen (N) and phosphorus (P) fertilizer requirements generally change very little compared to not harvesting stover, because at harvest the stover contains low concentrations of both nutrients. In contrast, potassium (K) tends to remain in the vegetive portion of the plant instead of being concentrated in the grain. As a result, when stover or other crop residue is harvested before most plant K has been translocated to the lower portion of the plant (i.e., by the time of grain and subsequent stover harvest) K removal can be quite high and increase the need for fertilizer input. In general, our studies have shown that harvesting the upper 50 or 60% of the corn plant as cellulosic feedstock will be sustainable, but again, using K removal data based on corn silage will over-estimate stover K removal. Harvesting herbaceous perennial feedstocks (switchgrass, miscanthus, CRP mixtures) in late autumn when the plants are fully mature and going into winter dormancy will generally minimize K removal because most of that nutrient will have been translocated back into the soil. Again, early harvest can result higher fertilizer requirements. Related research has shown that to further minimize nutrient removal, harvest can even be delayed until the following spring just before the perennials break dormancy.

Correlated environmental and ecosystem services

Sustainable SOC management through landscape design or any other soil and crop management change almost certainly have corresponding local and regional environment and ecosystem services co-benefits. Improved SOC management is anticipated to have beneficial water quality effects by reducing run-off and related sedimentation, improving nutrient retention and reducing leaching, and helping keep the soil covered with well-developed, stable aggregates that will reduce wind or water erosion. For example, decreased frequency and intensity of tillage will almost always increase SOC due to decreased tillage erosion. Plant available water quantity will also be modulated by avoiding run-off and increasing profile water storage. This can also reduce irrigation requirements and improve crop productivity. Air-quality co-benefits are realized when management for SOC sustainability reduces the amount of small airborne soil particulates. However, PM10 and PM2.5 issues associated with cellulosic feedstock harvest, storage, and transport (HST) as well as processing must be accounted for when assessing sustainability of the overall Landscape Design and production system. Finally, when sustainable SOC management results in diversification of the plant community through planting of cellulosic perennial feedstocks or conversion of cropland to Conservation Reserve Program (CRP) areas, ecosystem benefits will often include increases in faunal diversity, including desirable game birds and pollinator species.

Producer perspectives

In addition to Landscape Design implementation and management on SOC, critical human factors often not considered when answering technical soil or management questions need to be recognized and appropriately addressed. These human factors are no less important than the landscape design strategies being recommended to produce cellulosic feedstocks instead of traditional crops or the effects of those practices on sustainable SOC management. Among the most important human factors is assuring a stable and reliable market for cellulosic feedstock. In general producers care about safe-guarding their land and desire to know if the suggested practices are sustainable economically, agronomically, and environmentally. They need to balance among short, medium, and long-term consequences of their decision so they can pay the banker and provide for their family while navigating erratic weather patterns, long-term climate change, and a multitude of other time-demanding decisions. Furthermore, producers generally desire a lifestyle that is not fraught with regulations. They want to know who is responsible for ensuring the practices are truly sustainable, and how that sustainability will be assessed. Producers were a key part of the Landscape Design project, not only providing their insight and feedback, but also graciously agreeing to allow access to their farms for field research and measurements on their working lands. In return, each participating farmer was provided a detailed soil health assessment report based on samples collected on their land.

Throughout this entire project, producer participation and input were important because weather and time affect every Landscape Design decision (Dale et al., 2019). Fundamentally, producers simply want to know how cellulosic feedstock production will affect those factors before any decision can be made. They want to know how management changes (landscape design, cellulosic feedstock production, or simply changing the type and intensity of tillage) will affect his/her return on investment (ROI). Several producers also questioned if adding cellulosic feedstock to their cropping portfolio would require major equipment investment or other extensive management practices. Other consistent questions included: “are there viable third-party vendors to provide labor and equipment to plant, manage, and harvest feedstocks, thus reducing time demands?”; “Are there government programs that will help support these endeavors?” and “What are cost/benefit ratios for me?”

Finally, many Landscape Design questions go beyond individual producers and well beyond the dynamics of SOC management. We consider these to be questions having community impact. For example, proponents will often stress the opportunities to develop new employment, rural development, and market opportunities such as the potential sale of carbon credits. Others question how the change will affect (i) personal and family recognition; (ii) weed, insect, noise, rodent, and fire hazards; (iii) road, bridge and traffic patterns; and (iv) overall community labor supply. All are important questions and should be considered in well-designed Landscape Design projects.

Summary

Cellulosic bioenergy feedstock production with the landscape designed for sustainable SOC management was studied using a multi-faceted approach that addressed soil processes, as well as environmental, producer and community impacts. This final case study documents that without any doubt, SOC was an integral component of this Landscape Design project. The principles associated with the dynamics of SOC management are part of the Landscape Design process, but our perspective is that these principles not only influence and are affected by diversified landscape management, but also that they should be critical factors evaluated in every experiment and policy proposal associated with carbon management. This begins by recognizing that first and foremost, every soil and crop management practice affects and is affected by site-specific soil resource properties and processes, has the opportunity to provide environmental co-benefits, and needs to address producer perspectives and acknowledge potential community impacts to realize reliable and sustainable cellulosic feedstock supplies for bioenergy or other bio-products.

For supporting information on the impact of landscape design principles on SOC, other Case Study topics, or outcomes associated with this multi-Agency, participatory project, please see our accompanying website or contact any of the project organizers or contributors.

References

Dale, V. H., Kline, K. L., Parish, E. S, and Eichler, S. E. 2019. Engaging stakeholders to assess landscape sustainability: Experiences and insights. Landscape Ecology. DOI: 10.1007/s10980-019-00848-1. https://rdcu.be/bHFGF

Karlen, D. L., D. E. Stott, and M. M. Mikha. (eds.) 2021. Soil Health, Volume One: Approaches to Soil Health Analysis. Soil Science Society of America and Wiley International. ISBN: 978-0-891-18984-8 224 p.

Karlen, D. L., D. E. Stott, and M. M. Mikha. (eds.) 2021. Soil Health, Volume Two: Laboratory Methods for Soil Health Analysis. Soil Science Society of America and Wiley International.

Publications

Chen, H, Daib, Z., Jager, H. I., Wullschleger, S. D., Jianming, X., and Schadt, C. W. 2019. Influences of nitrogen fertilization and climate regime on the above-ground biomass yields of miscanthus and switchgrass: A meta-analysis. Renewable and Sustainable Energy Reviews 108: 303-311.

Cheng, H., Shu, K., Qi, Zi, Ma, L., Jin, V. L., Li, Y., Schmer, M. R., Wienhold, B. J., Feng, S. 2021. Effects of residue removal and tillage on greenhouse gas emissions in continuous corn systems as simulated with RZWQM2. Journal of Environmental Management. 285: 112097. https://doi.org/10.1016/j.jenvman.2021.112097.

Dale, V. H., Kline, K. L., Richard, T. L., Karlen, D. L., and Belden, W. W. 2018. Bridging biofuel sustainability indicators and ecosystem services through stakeholder engagement. Biomass and Bioenergy 114:143-156. https://doi.org/10.1016/j.biombioe.2017.09.016

Dale, V. H., Kline, K. L., Parish, E. S, and Eichler, S. E. 2019. Engaging stakeholders to assess landscape sustainability: Experiences and insights. Landscape Ecology. DOI: 10.1007/s10980-019-00848-1. https://rdcu.be/bHFGF

Dien, B. S., Mitchell, R. B., Bowman, M. J., Jin, V. L., Quarterman, J., Schmer, M. R., Singh, V., and Slininiger, P. J. 2018. Bioconversion of pelletized big bluestem, switchgrass, and low-diversity grass mixtures into sugars and bioethanol. Frontiers in Energy Research. 6: Article 129. https://doi.org/10.3389/fenrg.2018.00129

Ebadian. M., Sokhansanj, S. and Webb, E. 2017. Estimating the required logistical resources to support the development of a sustainable corn stover bioeconomy in the USA. Biofuels, Bioproducts, and Biorefining (Biofpr) 11:129-149.

Gollany, H. T., Nash, P. R., Johnson, J. M. F., Barbour, N. W., 2020. Predicted annual biomass input to maintain soil organic carbon under contrasting management. Agronomy Journal. 111:4822-4835. https://doi.org/10.1002/agj2.20068

Gorelick, D, Baskaran, L. M., and Jager, H. I. 2019. Visualizing feedstock siting in biomass production: tradeoffs between economic and water quality objectives. Land Use Policy 104201.

Graham C, Ramos-Pezzotti M., and Lehman, R. M. 2021. Short-term impacts to the soil microbial population during grassland conversion to cropland. Soil and Tillage Research 206: 104839. https://doi.org/10.1016/j.still.2020.104839

Griffel, L. M., Vazhnik, V., Hartley, D. S., Hansen, J. K., and Roni, M. 2020. Agricultural field shape descriptors as predictors of field efficiency for perennial grass harvesting: An empirical proof. Computers and Electronics in Agriculture, 168. https://doi:10.1016/j.compag.2019.105088

Ha, M., Wu, M., Tomer, M. D., Gassman, P. W., Isenhart, T. M., Arnold, J. G., White, M. J., Comer, K. S. and Belden, B. 2020. Biomass Production with Conservation Practices for Two Iowa Watersheds. Journal American Water Resources Association. https://doi.org/10.1111/1752-1688.12880.

Hansen, J. K., Roni, M. S., Nair, S. K., Hartley, D. S., Griffel, L. M., Vazhnik, V., and Mamun, S. 2019. Setting a baseline for Integrated Landscape Design: Cost and risk assessment in herbaceous feedstock supply chains. Biomass and Bioenergy, 130. https://doi:10.1016/j.biombioe.2019.105388

Ibrahim, V. E., Osborne, S. L., Schumacher, T. E., and Riedell, W. E. 2018. Corn residue removal effects on hydraulically effective macropores. Comm. Soil Sci. Plant Anal. https://doi.org/10.1080/00103624.2018.1464187

Jin, V. L., Schmer, M. R., Stewart, C. E., Sindelar, A. J., Varvel, G. E., and Wienhold, B. J. 2017. Long-term no-till and stover retention each decrease the global warming potential of irrigated continuous corn. Global Change Biology. 23:2848-2862.

Jin, V. L., Schmer, M. R., Stewart, C. E., Mitchell, R. B., Williams, C. O., Wienhold, B. J., Varvel, G. E., Follett, R. F., Kimble, J., and Vogel, K. P. 2019. Management controls the net greenhouse gas outcomes of growing bioenergy feedstocks on marginally productive croplands. Science Advances. Vol. 5, no. 12, eaav9318. https://doi:10.1126/sciadv.aav9318

Johnson, J. M. F. and Barbour, N. W. 2018. Stover harvest did not change nitrous oxide emissions in two Minnesota fields. Agronomy Journal. 111:143–155.

Kanter, D. R., Musumba, M., Wood, S. L. R., Palm, C., Antlee, J., Balvanera, P., Dale, V. H., Havlik, P., Kline K. L., Scholes, R. J., Thornton, P., Tittonellk, P., and Andelman, S. 2016. Evaluating agricultural trade-offs in the age of sustainable development. Agricultural Systems. https://www.researchgate.net/publication/309230139

Karlen, D. L. and Obrycki. J. F. 2018. Measuring rotation and manure effects in an Iowa farm soil health assessment. Agronomy Journal. 110:749-757. https://doi.10.2134/agronj2018.02.0113

Karlen, D. L., Schmer, M. R., Kaffka, S. R., Clay, D. E., Wang, M. Q., Horwath, W. R., Kendall, A. M., Keller, A., Pieper, B. J., Unnasch, S., Darlington, T., Vocasek, F. and Chute, A. G. 2019. Unraveling Crop Residue Harvest Effects on Soil Organic Carbon. Agronomy Journal 111:93-98. https://doi:10.2134/agronj2018.03.0207

Kreig, J. F. A., Chaubey, I., Ssesane, H., Negri, C. M.. and Jager, H. I. 2019. Designing bioenergy landscapes to protect water quality. Biomass & Bioenergy 128 105327.

Lai, L., Hong, C.O., Kumar, S., Osborne, S. L., Lehman, R. M., and Owens, V. 2018. Soil nitrogen dynamics in switchgrass seeded to a marginal cropland in South Dakota. Global Change Biology Bioenergy 10:28-38; https://doi.org/10.1111/gcbb.12475

Lidong, L., Jin, V. L., Timothy Kettler, T., Karlen, D. L., Nunes, M. R., Lehman, R. M., Johnson, J. M. F., and Mikha, M. M. Decreased land use intensity improves surface soil quality on marginal lands. Agrosystems, Geosciences & Environment. (in press; accepted for publication 10-25-2021).

Locker, C. R., Torkamani, S., Laurenzi, I. J., Jin, V. L., Schmer, M. R., and Karlen, D. L. 2019. Field-to-Farm Gate Greenhouse Gas Emissions from Corn Stover Production in the Midwestern U.S. Journal of Cleaner Production. 226:1116-1127. https://doi:10.2134/agronj2018.03.0207

Malone, R. W., Obrycki, J. F, Karlen, D. L., Ma, L., Kaspar, T. C., Jaynes, D. B., Parkin, T. B., Lence, S. H., Feyereisen, G. W., Fang, Q. X., Richard, T. L., and Gillette, K. 2018. Harvesting fertilized rye cover crop: Simulated revenue, net energy, and drainage nitrogen loss. Agricultural and Environmental Research Letters 3:170041. https://doi:10.2134/ael2017.11.0041

Malone, R. W., Herbstritt, S., Ma, L., Richard, T. L., Cibin, R., Gassman, P. W., Zhang, H. H., Karlen, D. L., Hatfield, J. L., Obrycki, J. F., Helmers, M. J., Jaynes, D. B., Kaspar, T. C., Parkin, T. B., and Fang, Q. X. 2019. Corn stover harvest N and energy budgets in central Iowa. Science of the Total Environment. 63:776-792. https://doi.org/10.1016/j.scitotenv.2019.01.3280048-9697

Mamun, S., Hansen, J. K., and Roni, M. S. 2020. Supply, operational, and market risk reduction opportunities: Managing risk at a cellulosic biorefinery. Renewable and Sustainable Energy Reviews, 121. https://doi:10.1016/j.rser.2019.109677

Mikha, M. M., Jin, V. L., Johnson, J. M. F., Lehman, R. M., Karlen, D. L., and Jabro, J. 2021. Land Management Effects on Wet Aggregate Stability and Carbon Content. Soil Science Society of America Journal. https://doi.org/:10.1002/saj2.20333

Novak, J. M., Frederick, J. R., Watts, D. W., Ducey, T. F. and Karlen, D. L. 2021. Corn Stover Removal Responses on Soil Test P and K Levels in Coastal Plain Ultisols. Sustainability 2021, 13, 4401. https://doi.org/10.3390/su13084401

Nunes, M. R., Veum, K. S., Parker, P. A., Holan, S. H., Karlen, D. L., Amsili, J. P., van Es, H. M., Wills, S. A., Seybold, C. A., Moorman, T. B. 2021. The Soil Health Assessment Protocol and Evaluation Applied to Soil Organic C. Soil Science Society of America Journal. 85:1196–1213. https://doi.org/10.1002/saj2.20244

Nunes, M. R., De, M., McDaniel, M., Kovar, J. L., Birrell, S. J., and Karlen, D. L. 2021. Science-Based Maize Stover Removal Can Be Sustainable. Agronomy Journal. 113:3178–3192. https://doi.10.1002/agj2.20724

Nunes, M. R., de Lima, R. P., Tormena, C. A., and Karlen, D. L. 2021. Corn seedling root growth response to soil physical quality. Agronomy Journal. 113:3135–3146 https://doi:10.1002/agj2.20705

O'Brien, P. L., Sauer, T. J., Archontoulis, S., Karlen, D. L., and Laird, D. 2020. Corn stover harvest reduces soil CO2 fluxes but increases overall C losses. Global Change Biology Bioenergy 12:894-909. https://doi/10.1111/gcbb.12742

Obrycki, J. F. and Karlen, D. L. 2018. Is Corn Stover Harvest Predictable Using Farm Operation, Technology, and Management Variables? Agronomy Journal. 110:749–757. https://10.2134/agronj2017.08.0504

Obrycki, J. F., Karlen, D. L., Cambardella, C. A., Kovar, J. L., and Birrell, S. J. 2018. Corn stover harvest, tillage, and cover crop effects on soil health indicators. Soil Science Society of America Journal 82:910-918. https://doi:10.2136/sssaj2017.12.0415

Obrycki, J. F., Kovar, J. L., Karlen, D. L., and Birrell, S. J. 2018. Ten-year assessment encourages no-till for corn grain and stover harvest. Agricultural and Environmental Letters. 3:180034. https://doi:10.2134/ael2018.06.0034

Obrycki, J. F. and Karlen, D. L. 2018. Optimizing Iowa land use: Past perspectives for current questions. Journal of Soil and Water Conservation 73:693-704. https://doi:10.2489/jswc.73.6.693

Obrycki, J. F., Kovar, J. L., and Karlen, D. L. 2018. Subsoil potassium in central Iowa soils: status and future challenges. Agroecosystems Geoscience and Environment. 1:180018. https://doi:10.2134/age2018.07.0018

Ojekanmi, A., and Johnson, J. M. F. (2020). Quantifying improvements in water stable aggregation due to corn stover retention. Soil Science Society of America Journal. In press. https://doi.org/10.1002/saj2.20198.

Parish, E., Dale, V., Davis, M., Efroymson, R., Hilliard, M., Jager, H., Kline, K., and Xie, F. In Press. An indicator-based approach to sustainable management of natural resources. Chapter 13 in Data Science Applied to Sustainability Analysis. Edited by Dunn, J. and Balaprakash, P. Elsevier https://doi:10.1016/C2018-0-02415-9

Reichmann, L. G., Collins, H. P., Jin, V. L., Johnson, M-V. V., Kiniry, J. R., Mitchell, R. B., Polley, H. W., and Fay, P. A. 2018. Inter-annual precipitation variability decreases switchgrass productivity from arid to mesic environments. Bioenergy Research 11: 614-622.

Schmer, M. R., Brown, R. M., Jin, V. L., Mitchell, R., and Redfearn, D. D. 2017. Corn residue utilization by livestock in the USA. Agricultural and Environmental Letters. 2:160043.

Schmer, M.R. Jin, V. L., Ferguson, R. B., and Wienhold, B. J. 2020. Irrigation, carbon amelioration, nitrogen, and stover removal effects on continuous corn. Agron. J. 112:2506-2518. https://doi:10.1002/agj2.20192

Bhavna Sharma, B., Clark, R., Hilliard, M. R., and Webb, E. G. 2018. Simulation Modeling for Reliable Biomass Supply Chain Design Under Operational Disruptions. Front. Energy Res. 6:100. https://doi:10.3389/fenrg.2018.00100

Sieverding, H., Kebreab, E., Johnson, J. M. F., Xu, H., Wang, M., Del Grosso, S. J., Bruggeman S. Stewart, C., Westhoff, S., Ristau J., Kumar S., and Stone, J. J. 2020. A life cycle analysis (LCA) primer for the agricultural community. Agronomy Journal, 112(5), 3788-3807. https://doi:10.1002/agj2.20279

Sindelar, M., Blanco, H., Jin, V. L., and Ferguson, R. 2019. Cover crops and corn residue removal: impacts on soil hydraulic properties and their relationships with carbon. Soil Science Society of America Journal. 83:221–231. http://doi:10.2136/sssaj2018.06.0225

Sindelar M., Blanco, H., Jin, V. L., and Ferguson, R. 2019. Do cover crops and corn residue removal affect soil thermal properties? Soil Science Society of America Journal. 83:448-457. https://doi:10.2136/sssaj2018.06.0239

Stetson, S. J., Lehman, R. M. and Osborne, S. L. 2018. Corn residue particle size impacts soil surface properties. Agricultural and Environmental Letters. 3:180004 https://doi:10.2134/ael2018.01.0004

Stewart, C. S., Roosendaal, D. L., Sindelar A. J., Pruessner, E., Jin V. L., and Schmer, M. R. 2019. Does no-tillage mitigate stover removal in irrigated continuous corn? A multi-location assessment. Soil Science Society of America Journal. 83:733-742. https://doi:10.2136/sssaj2018.09.0352

Vazhnik, V. 2020. Farm Landscape Design Decision Support to Increase Economic, Environmental and Social Benefits Using Stakeholder Engagement, Sustainability Assessment and Spatial Analysis. Dissertation in BioRenewable Systems for The Pennsylvania State University. 230 pages.

Wegner, B. R., Osborne, S. L., Lehman, R. M., and Kumar, S. 2018. Seven-year impact of cover crops on soil health when corn residue is removed. BioEnergy Research. 11:1-9. https://doi.org/10.1007/s12155-017-9891-y

Wegner, B. R., Subedi K., Singh, S., Lai, L., Abagandura G., Kumar, S., Osborne, S.L., Lehman, R.M., and Jagadamba, S. 2018. Response of soil surface greenhouse gas fluxes to crop residue removal and cover crops under a corn-soybean rotation. Journal of Environmental Quality 47:1146-1154. https://doi:10.2134/jeq2018.03.0093

Xu, H., Sieverding, H., Kwon, H., Clay, D., Stewart, C., Johnson, J. M. F., Qin, Z., Karlen, D. L., and Wang, M. 2019. A global meta-analysis of soil organic carbon response to corn stover removal. Global Change Biology – Bioenergy 11, 1215-1233. https://doi:10.1111/gcbb.12631