Selecting indicators of changes in ecosystem services due to cellulosic-based biofuel in the midwestern US

Authors: Virginia H. Dale, Keith L. Kline, Tom L. Richard and Doug L. Karlen

For special issue of Biomass and Bioenergy on "Biofuels and Ecosystem Services" organized by Alexandros Gasparatos at the University of Tokyo - http://www.journals.elsevier.com/biomass-and-bioenergy/call-for-papers/special-issue-on-using-the-ecosystem-services-approach-to-as/

Submitted: April 24, 2016

Highlights: <limited to 85 characters including spaces per item>

- Eleven categories of indicators are identified to measure sustainability.
- Environmental concerns are soils, water, GHG, biodiversity, and productivity.
- Socioeconomic concerns include wellbeing, trade, profit, and social acceptability.
- Provisioning, cultural, regulating, and supporting services can be assessed.

Abstract: Cellulosic-based biofuels are needed to help meet energy needs and to strengthen rural investment and development in the midwestern United States (US)**.** This analysis identifies 11 categories of indicators to measure progress toward sustainability that should be monitored to determine if ecosystem and social services are being maintained, enhanced, or disrupted by production, harvest, storage, and transport of cellulosic feedstock. The indicator categories are identified using scientific literature, input from two stakeholder meetings, and response information from targeted surveys. Five of the categories focus on environmental concerns (soil quality, water quality and quantity, greenhouse gas emissions, biodiversity, and productivity), and six focus on socioeconomic categories (social well-being, energy security, external trade, profitability, resource conservation, and social acceptability). We hypothesize that by measuring these indicators, it will be feasible to quantify changes in ecosystem and social services related to provisioning (e.g., energy, nutrition and materials), cultural, regulating, and supporting services such as optimum soil water and nutrient balances, remediation of wastes, toxins, or other nuisance compounds, and continuation of physical, biological and chemical conditions. To advance our hypothesis from conceptual to real-world sustainability assessments, the next step will be to work with a team of stakeholders and researchers to implement a Landscape Design Project entitled "E*nabling Sustainable Landscape Design for Continual Improvement of Operating Bioenergy Supply*

Systems." The desired outcome is to identify a science-based approach so that progress toward sustainability can be assessed and useful management practices can be identified.

Keywords: bioenergy, ecosystem services, landscape design, social services, sustainability

1. Introduction

Ecosystem and social services provide a useful viewpoint from which to consider trade-offs associated with biofuel production and use [1]. Biofuel systems can provide a variety of services such as fuel and climate regulation but can also affect other services such as food and water services in positive or negative ways [2, 3]. Environmentally, economically and socially sustainable technologies to produce liquid fuels from plant biomass are considered an essential element of sustainable development strategies [4, 5]. Some activities such as aviation, ocean shipping, and long-haul trucking require liquid fuels [6]. While biofuels are only one part of the energy portfolio, they are essential to achieving a sustainable transportation sector [6].

International growth of bioenergy industries has led to scientific and public interest in determining how production and use of bioenergy affect ecosystem and social services. The natural resource basis for these industries is cellulose, hemicellulose, or lignin derived from crop and forest residues, perennial grasses, urban waste materials, and other sources. Achievement of environmental benefits in the use of cellulosic-based biofuels depends on which, where, and how cellulosic biofuels are produced [4, 7]. In the United States and elsewhere throughout the world, legislative mandates associated with cellulosic ethanol production and adoption of renewable transportation fuels require quantitative assessment of changes to ecosystem and social services that occur as a result of bioenergy production and use [8].

From an ecosystem services perspective, cellulosic-based biofuel production can positively or negatively affect provisioning services such as food, feed, and fiber; cultural services such as secure jobs, scenery, and outdoor activities; and regulating and supporting services such as (a) mediation of water and nutrient flows, (b) mediation of wastes, toxins, and other nuisances, and (c) maintenance of physical, biological and chemical conditions. Positive and negative effects of biofuel feedstock production and use are context specific [9], and therefore it is not possible to make general statements regarding costs or benefits of cellulosic-based biofuels on ecosystem services. Rural producers and local stakeholders include anyone positively or negatively affected by changes in ecosystem services. It is crucial to obtain their views to fully comprehend regional implications regarding biofuel development within rural landscapes [10].

This paper reports on the identification of relevant environmental and social indicator categories of progress toward bioenergy sustainability for a project funded by the US Department of Energy (DOE) entitled "*Enabling Sustainable Landscape Design for Continual Improvement of Operating Bioenergy Supply Systems"* (and referred to below as the Landscape Design Project). The overall goal of the Project is to integrate bioenergy production into other components of environmental, social and economic systems while addressing sustainability concerns [11]. The Project is working to identify a science-based approach for quantitatively evaluating positive and negative effects of feedstock production, harvest, storage, and transport within two specific biofuel feedstock supply sheds that might be generally applicable to cellulosic-based biofuel production in other areas. The initial implementation focuses on production of ethanol using corn (*Zea mays* L.) stover and perennial grasses in the midwestern US state of Iowa. Specifically, the project considers feedstock supply sheds for two operating biorefineries: Poet-DSM's Project LIBERTY near Emmetsburg, Iowa, and the DuPont cellulosic biorefinery near Nevada, Iowa (Figure 1). Project LIBERTY is designed to convert baled corn stover (cobs, leaves, husks and stalks) into cellulosic-based ethanol. Current design capacity will convert 770 tons of biomass per day into 462 thousand barrels (20 million gallons) of ethanol per year, later ramping up to 575 thousand barrels (25 million gallons) per year. The DuPont biorefinery is designed to produce up to 694 thousand barrels (30 million gallons) of ethanol each year, which would make it the largest cellulosic-based ethanol production plant in the world. In early 2016, both plants were in early phases of operation with modest output. The two biomass supply sheds supporting these bio-refineries are located within areas dominated by corn and soybean [*Glycine max* (L.) Merr.] production and where both surface and tile drainage water flows into the Des Moines River or one of its tributaries or directly into the Mississippi River through either the Iowa or Cedar Rivers and associated tributaries. These areas have received significant attention regarding water quality challenges due to high nitrate nitrogen (NO_3-N) and elevated phosphorus (P) concentrations [12, 13, 14, 15]. In addition, midwestern US agriculture has been linked to changes in the hypoxia zone within the Gulf of Mexico [16, 17].

There has not been adequate legislative, executive, or regulatory response to reverse the trend of increasing nitrogen loads established during the latter half of the 20th century in response to changes in cropping patterns [18], drainage, annual precipitation, or N fertilizer rates. Many studies in the upper Midwest confirm that over 90% of the NO_3-N entering Iowa streams comes from agricultural sources as set forth in the Iowa Nutrient Reduction Strategy [19].

In 2014, the city of Des Moines' Water Works (DMWW) Department filed suit in Federal court against County Supervisors in three counties in the future Poet-DSM biomass supply shed because of high NO_3-N concentrations in drainage water entering the Raccoon River [20]. The DMWW is a regional utility that provides water to approximately one-half million Iowans and obtains its raw water supply from the Raccoon and Des Moines Rivers through direct river intake and access to shallow alluvial aquifers and surface waters recharged by those rivers. The suit states that the Raccoon and Des Moines Rivers have suffered a long-term increase in levels of pollution, particularly NO_3-N, which can only be removed by water treatment plants. DMWW has invested millions of dollars in capital infrastructure, including a NO_3-N removal facility built in the early 1990s for $4.1 million but designed to operate an "as needed" basis when NO_3-N concentrations do not comply with the Environmental Protection Agency's (EPA) 10 mg L^{-1} maximum contaminant level (MCL) rule under the Safe Drinking Water Act. Even so in 2013, DMWW issued a voluntary conservation request to its customers for 74 days during peak summer demand, and in 2014 the NO3-N load again set record levels.. The NO_3-N removal facility costs over $7000 day^{-1} to operate.

Given the challenges associated with policy solutions to non-point source water pollution, there is strong interest in exploring market-based strategies. Perennial grasses planted as buffers can reduce nutrient, phosphorous and sediment loads. A landscape-scale study in Iowa indicates that planting 10%

of cropland in perennial buffers can reduce N by 80% and P and sediment by 90% [21]. With the advent of commercial scale cellulosic biofuel in the same region of Iowa that is experiencing water quality challenges, we hypothesize that agricultural-production systems that stabilize the availability of bioenergy feedstock supplies could also provide an economic incentive for increased production of perennial crops and thus help mitigate water quality concerns throughout both biomass supply sheds.

In 2015, the US Department of Energy initiated a Landscape Design Project to test this hypothesis. The Landscape Design Project will engage stakeholders to implement commercial-scale, integrated, land management systems that exploit synergies between cellulosic feedstocks and water quality on thousands of hectares in central Iowa. The hope is that the combination of market demand for perennial biomass, conservation payments to establish perennials, and farmer/landowner/community interest in documenting environmental, social and economic benefits will combine to incentivize widespread positive changes in agricultural practices and performance. An initial step of this project is to identify key indicators of changes in water quality and other ecosystem services and thus determine how biofuel production throughout the region might affect services. Eventually it is hoped that the project will generate management strategies to accomplish that goal, provide information that could offer solutions within the region and nationwide, and demonstrate innovative ways to support a sustainable bioeconomy. This effort will build on prior work on large-scale herbaceous biomass supply chains that have identified three principal priorities: cost efficiency, reliability of supply, and sustainability [22]. However, to date, sustainability is often undefined.

Ssuch complex problems call for meaningful indicators and their effective use to support informed decisions [23,27]. While addressing both feedstock production and water quality as an integrated agricultural system, it is important to focus on key measures rather than a plethora of diverse indicators that can confuse rather than inform decision-makers [24]. Agreement with stakeholders on a few common measures for a specified context is essential to identify key effects on ecosystem and social services [11]. Many assessments do a poor job of determining metrics to be measured, and, as a result, analysis is biased by information available and the perspective of the assessment team. By taking a holistic view of potential changes in services and metrics that measure those changes, this analysis is expected to be less biased.

The question addressed here is what categories of indicators should be used to quantify changes in ecosystem and social services associated with cellulosic-based biofuel production in the midwestern US. Identifying relevant indicators of changes in services for this region focuses efforts to enhance benefits and improve market opportunities for energy crops as well as addresses environmental concerns. This analysis draws from a checklist of indicators of progress toward sustainable bioenergy [25,26] that relate to supporting, regulating, cultural, production, and provisioning aspects of ecosystem services (Table 1 and 2).

To identify appropriate indictors, this project uses a framework for selecting indicators for particular contexts [27], which emphasizes the importance of stakeholder engagement throughout the process. Overall, this project is intended to provide an example of how a landscape design approach can have immediate benefits not only for bioenergy feedstock production and water quality issues but also by identifying key indicators of ecosystem and social services for cellulosic based-biofuels in the midwestern US.

2. Data collection and study method

This Landscape Design Project focuses on biomass feedstock supply sheds serving the Poet-DSM's Project LIBERTY biorefinery near Emmetsburg, Iowa, and the DuPont cellulosic biorefinery near Nevada, Iowa (Figure 1). Both supply sheds are representative of the ecosystems associated with the US Corn Belt, a region known for its high production of corn and characterized by deep, rich soils and a temperate climate.

The proposed indicators were identified using survey responses from a November 2015 conference, information collected during the Landscape Design Project kickoff meeting in December 2015, and a December 2015 stakeholders meeting in Des Moines, IA. Collectively these three sources of information provide perspectives of stakeholders throughout both supply sheds and the Midwest region as a whole. In addition, other scientific studies of biofuel production using corn stover and perennial grasses in the midwestern US are included in this analysis. Information regarding these sources is presented below.

On November 19-20, 2015, 175 participants attended a conference entitled "Sustaining Our Iowa Land (SOIL): Past, Present and Future of Iowa's Soil Water Conservation Policy" at Drake University Law School in Des Moines, Iowa [28]. The conference was developed by the Drake Agricultural Law Center in cooperation with the Leopold Center for Sustainable Agriculture. Participants included a wide range of individuals and representatives of organizations who are working to protect Iowa's soil and water resources. Participants considered the roles that policy and law play in shaping stewardship efforts and were asked 20 questions about soil and water conservation. All responses are posted at the conference website [29].

The December 1 to 3, 2015, Landscape Design Project kickoff meeting was organized by Antares Group Inc., who is leading the project, supported by the Bioenergy Technologies Office of DOE's Office of Energy Efficiency and Renewable Energy. Meeting participants included farmers as well as representatives from the Iowa Rural Water Association, Iowa Department of Natural Resources, Iowa State University Extension Service, Iowa Farm Bureau and affiliates, Iowa Corn Growers and Iowa Soybean Association, drainage district officials, crop consultants, farm management firms, the biorefineries, and agricultural agencies such as the Iowa Department of Land Stewardship (IDALS), Natural Resources Conservation Service (NRCS), and the Iowa State Farm Service Agency (FSA). In addition, the meeting included researchers from DOE's Bioenergy Technologies Office, Idaho National Laboratory, Iowa State University, Oak Ridge National Laboratory, Pennsylvania State University, Purdue University, and the US Department of Agriculture (USDA) who are familiar with changes in services associated with all aspects of biofuel production. One objective of the meeting was to identify local priorities and needs that could potentially be addressed by the research project. The attendees were queried regarding their perspectives and priorities associated with several potential indicators of progress toward economically and socially sustainable biofuel feedstock supply chains. The tool ThinkTank®, a software system for real time collection of ideas that allows for parallel input collaboration, synchronous and asynchronous session support, user anonymity, and assessment, was used to enhance participation and information collection.

On December 3, 2015, 34 regional stakeholders concerned about the pending lawsuit participated in a meeting titled “Capital Crossroads: A Vision Forward” [30]. The group is focused on a vision for the future of the Greater Des Moines and Central Iowa area that honors stewardship of natural resources for a clean and sustainable environment. These stakeholders expressed substantial concern about nutrient runoff from farms and drainage districts that appear to be contributing to the record levels of NO_3-N in the Raccoon River. Five presentations and a discussion focused on concerns about water quality impact of agricultural practices and how to address them provided additional input for this analysis.

Recognizing the breath of potential stakeholder viewpoints, perspectives of stakeholders not represented by the November 2015 survey, December research meeting, or stakeholder session) were accounted for by using a literature review and direct queries to selected stakeholders. Targeted perspectives include the recreational community and those affected by changes in air quality.

3. Results and discussion

Biofuel production can provide a positive economic opportunity for agricultural regions including most rural communities in the Great Plains and Midwest that have suffered from declining populations, incomes, and social resources [31]. A 2011 community case study that examined local perceptions regarding costs and benefits of the ethanol industry in Iowa found not only modest economic benefits and employment increases in those communities establishing ethanol plants but also increased traffic, water competition, and social vulnerabilities if the biofuel industry does not prove to be viable [10]. Another study of farm and non-farm participants involved with a switchgrass biofuel project in southern Iowa found local and regional revitalization being the benefit most desired as well as least expected [10]. The results and literature discussed below provide additional insights to what stakeholders view as important aspects of a sustainable bioeconomy in Iowa.

3.1 Survey results

The survey results reveal great concern regarding water quality, soil erosion, and the need for conservation plans (Figure 2). More than 71% of the respondents agree that Iowa's current laws and regulations concerning water quality are inadequate to prevent the pollution of rivers and streams. Almost 43% of the respondents think it is impossible to implement effective soil and water conservation efforts if farming systems are based only on a corn and soybean rotation, and an additional 18% were uncertain about this option. While 68% of the respondents agreed that farm land owners should be required to have a current conservation plan developed by USDA’s Natural Resource Conservation Service (NRCS) or the local Soil and Water Conservation District (SWCD), only 35% of the respondents thought that soil erosion is being adequately prevented via compliance with a conservation plan and federal conservation rules. Respondents suggested that central Iowa water quality could be improved by transitioning to either reduced- or no- tillage operations, installing buffer strips, planting cover crops, implementing watershed-based nutrient management goals (e.g., reduced N and P application rates), increasing educational opportunities and perhaps enforcing conservation plans (Table 3). These options can all be implemented using biofuel crops to improve ecosystem services. For example, biofuel crops planted in buffer strips could provide effective surface cover and protection against wind and water erosion, thus enabling greater collection of corn stover feedstock and enabling no-till land management. The survey results also emphasize that the challenges associated with addressing water quality in the region are multifaceted.

3.2 Landscape Design project kickoff meeting

Participants at the Landscape Design meeting used ThinkTank® to select the social, environmental and economic aspects that they thought were of highest priority (Figures 3 and 4). The social aspects of concern included perceptions such as risk of catastrophe (e.g., floods), effective stakeholder participation, transparency, and public opinion, as well as social well-being (e.g., household income, food security, employment, and work days lost to injury). Their responses underscored that farmers' perceptions and risk aversion can significantly influence biofuel feedstock options [32] and their willingness to produce, harvest, store and transport biofuel crops for biorefineries or other markets.

Regarding the environmental aspects, productivity, greenhouse gases, water quantity and quality as well as soil quality or health and their effects on ecosystem services are the primary concerns (Table 1). Harvesting of corn stover affects nutrient removal and replacement cost [33, 34], feedstock quality [35, 36, 37, 38], soil fertility and soil quality [39, 40, 41]. The appropriate corn stover removal rate is site- and even sub-field specific as influenced by soil type, stover price, harvest cost, and other factors [42]. Therefore, producers should have good soil-test and nutrient management records for their harvest sites prior to initiating any harvest strategy [43]. Cellulosic ethanol is one of the cleanest-burning fuels available and can reduce carbon emissions by 90% over traditional fossil fuels. Participants recognized that corn stover removal can affect soil erosion, water quantity and quality, and soil nitrate nitrogen concentrations at the watershed scale [44], but none identified biodiversity or air quality as an important issue even though those topics have been highlighted in prior biofuel studies throughout this region [45,46].Using perennial grasses for feedstock production can enhance biodiversity [47,48,49,50,51] and recreational uses of water depend on healthy stream ecosystems. Therefore, biodiversity is retained as a category for assessment. However, subsequent analyses found that air pollutant emission regulations are estimated to have a minimal effect on costs of selection of the refinery site for cellulosic based biofuel [52, 53]. Given limited resources and the fact that other categories were considered to be higher priority for stakeholders, the air quality category is not included in our analysis. However, air emissions could still be considered to some degree for some locations as cellulosic production increases to higher production volumes. In doing so, analysis need to be careful to compare cellulosic-based biofuel to appropriate alternatives and not confuse it with emissions using ethanol derived from corn grain [54].

Among the economic indicators, profit was identified as a priority by 43% of the respondents, and energy security was also important as noted by 34% or respondents. While trade was not selected as a key issue by any of the respondents, it certainly affects biofuel sustainability. For example, trade is a key determinant of investment and price, and an analysis in 2011 found that Iowa farmers were still learning about corn stover harvesting but believe that it will require capital investment, additional knowledge, and a support infrastructure [55]. Producer willingness and ability to supply biomass varies depending on across crops and price level [56] as well as weather conditions [8]. Hence we include all socioeconomic categories listed in Table 2 (social well-being, energy security, trade, profitability, resource conservation, and social acceptability).

3.3 Stakeholder meeting

The stakeholder group was well-informed about the interactions among land-management practices, soil erosion, and water quality. Hence a focus on soil health was advocated. It was noted that improvements can be achieved via use of cover crops and keeping livestock on the land (for pasture was the original cover crop).

Engagement of agricultural retailers was an interesting twist brought to the discussion. Businesses are being established to provide farmers with data analytics and phone or computer applications that help identify improved practices and develop site-specific management plans with minimal effort. This business-based approach appears to effectively engage landowners in soil and water conservation. Ag retailers can provide tools for water and sediment control, options for constructed wetlands, soil loss calculators, and make spatially explicit recommendations of optimal locations and rates for fertilization application and stover collection. Such tools can be an important component of comprehensive planning efforts that enable enhancement of ecosystem services. And ongoing assessment of key indicators is a critical part of effective planning and implementation of conservation management strategies.

One participant effectively demonstrated erosion potential by pouring water over a glass of soil from no-tilled land (which remained largely intact) compared to that from tilled land (which disintegrated). Subsequent discussion focused on how improving soil health can be addressed by no-till practices, using cover crops, and keeping livestock on the land (noting that pasture was the original cover crop). The importance of education was emphasized by several participants.

Studies in other locations find that visual impact on the landscape and the rotation period of the energy crop have a significant effect on the perceived benefit derived from growing an energy crop [57]. Further, improved utility of a crop expressed in terms of secure demand and diversified markets can increase the area planted in that crop and the income associated with it [57].

3.4 A shortcut for stakeholder engagement

Stakeholder engagement is a priority in sustainability standards for bioenergy, yet is time consuming and costly. This paper presents an approach to establishing stakeholders' perspectives that is time efficient and less costly than extensive surveys or focus groups. We use available reports and meetings, and provide a written synopsis proposing indicators and inviting comments. While this approach is not ideal for achieving direct engagement of all stakeholders in the key research question, it is cost effective and uses stakeholders' opinions obtained via indirect means. This alternative can be useful to narrow the indicators of concern within a defined context.

Ongoing stakeholder education and continual improvement is a hallmark of sustainability. By publishing the results now, we seek comments and further input on key measures of progress toward sustainability of biofuels in the Corn Belt. This approach is amenable to outreach via social media tools that offer new ways to engage diverse stakeholders who may not attend meetings. Another example of this approach occurred when writing the novel The Martian, as the author posted drafts on line and vetted technical options to obtain input on plausible solutions and thereby improve details iteratively.

Stakeholder engagement is important, but input is not always obtained. The approach presented in this paper is a first step toward engagement of stakeholders in an ongoing process. While sustainability assessment efforts typically commence by collecting information on a particular component of the system, it is better to first identify key components and thereby select what to measure.

4. Conclusions

It is still early enough in the development of biofuel projects in Iowa watersheds for effects on key ecosystem and social services to be identified and benefits enhanced. Information on potential changes in services is needed by biomass harvesters, landowners, and local government so that sustainable harvest and cropping practices can be developed for places vulnerable to both wind and water erosion and where good crop residue management is needed to capture and retain rainfall and irrigation water.

Based on the November 2015 survey and December 2015 landscape design and stakeholder meetings as well as scientific literature, we identified major categories of indicators of progress toward biofuel sustainability for cellulosic crops in Iowa. Of the six proposed environmental categories [25], soil quality, water quality and quantity, greenhouse gases, biodiversity, and productivity were found to be the most important (Table 1). Air quality did not rise to same level of importance because concerns about biofuel-related effects on air quality were not expressed by the stakeholder group, landscape design meeting participants, or in the literature [52]. All of the proposed categories of socioeconomic indicators [26] were deemed important for cellulosic-based biofuel in Iowa (Table 2). Social wellbeing of the rural life style as well as the urban community is a concern of all groups. Energy security underlies economic security of the region and is promoted by stability of energy feedstock supply, stability of product and co-product supply and demand, and flexibility of the feedstock and fuel system [26]. External trade is a critical part of the Corn Belt economy, for most of its goods are shipped outside of the region. Profitability is pertinent to sustainability of the entire supply chain. Resource conservation refers to the conservation of all of Earth's resource and, in particular, fossil fuels. Social acceptability includes aesthetic values, recreational values, cultural values, and risks as public perceptions about those risks. Together, a suite of measures from these 11 categories can be used to monitor changes in sustainability attributes that are of concern to diverse stakeholders in Iowa and relevant to the expansion of cellulosic-based biofuel production. These 11 categories also cover key ecosystems services that might be affected by expansion of cellulosic-based biofuels in Iowa (Tables 1 and 2). The next step is to work with stakeholders and other researchers to identify reference and target conditions and collect data pertinent to indicators constituting these 11 categories with which effects on ecosystem and social services can then be assessed. This work will help identify management practices that can be implemented to improve ecosystem and social services.

Acknowledgements

This research was supported by the U.S. Department of Energy (DOE) under the Bioenergy Technologies Office. Oak Ridge National Laboratory is managed by the UT-Battelle, LLC, for DOE under contract DE-AC05-00OR22725. The authors appreciate Kevin Comer for his leadership on the Landscape Design Project, Alan G. Chute for administering the survey at the December 2015 meeting and suggestions for the draft manuscript, and Kristen Johnson for her comments, vision, and overview of the sustainability and analysis platform of DOE's Bioenergy Technologies Office.

Figures

1. Map of study area in central Iowa (provided by Antares Group Inc.). The two biomass supply sheds are defined by an 80 km (50 mile) radius from each biorefinery and occur in areas dominated by corn and soybean production and where surface water flows into the Des Moines River or its tributaries. Local watershed associations and their stakeholders in these two supply sheds are committed to identifying ways to leverage various projects and programs to help improve water quality and to develop market opportunities for herbaceous energy crops with known and recognized conservation benefits. The biomass feedstocks being focused on include corn stover and mixed warm season grasses such as switchgrass (*Panicum virgatum*), big bluestem (*Andropogon gerardii*), and Indian grass (*Sorghastrum nutans*).

2. Histogram of selected results from survey conducted by the Drake University Law School at the November 2015 conference on "Sustaining Our Iowa Land (SOIL): Past, Present and Future of Iowa's Soil Water Conservation Policy."

3. Percent of priority indicators for assessing progress toward bioenergy sustainability that were selected in each of three areas by 30 landscape design meeting participants.

Tables

1. List of recommended environmental indicators for bioenergy sustainability (based on McBride et al. 2013) and associated ecosystem service.

2. List of recommended socioeconomic indicators for bioenergy sustainability (based on Dale et al. 2015) and associated ecosystem service.

3. Selected responses to query about one big idea in Drake University survey that are pertinent to bioenergy production.

Table 1. List of recommended environmental indicators for bioenergy sustainability (based on McBride et al. 2013) and associated ecosystem service for assessing of effects on ecosystem services of cellulosic-based biofuels in the Midwestern US.

Environmental sustainability category	**Ecosystem service category:** type	**Indicator**	**Units**	**Related management pressures**	**Potential related environmental effects**
Soil quality	**Supporting and regulating service:** soil quality	1. Total organic carbon (TOC)	Mg/ha	Crop choice, tillage	Climate change, N mineralization, humification, water holding capacity, infiltration, CEC
		2. Total nitrogen (N)	Mg/ha	Crop choice, tillage, N fertilizer application, harvesting practices	Eutrophication potential, N availability
		3. Extractable phosphorus (P)	Mg/ha	Crop choice, tillage, P fertilizer application, harvesting practices	Eutrophication potential, P availability
		4. Bulk density	g/cm^3	Harvesting practices, tillage, crop choice	Water holding capacity, infiltration, crop nutrient availability
Water quality and quantity	**Regulating service:** drinking water; **Cultural service:** recreation	5. Nitrate concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr	Crop choice, % of residue harvested, tillage, N fertilizer application	Eutrophication, hypoxia, potability
		6. Total phosphorus (P) concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr	Crop choice, % of residue harvested, tillage, P fertilizer application	Eutrophication, hypoxia
		7. Suspended sediment concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr	Crop choice, % of residue harvested, tillage	Benthic habitat degradation through siltation, clogging of gills and filters
		8. Herbicide concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr	Crop choice, herbicide application, tillage	Habitat degradation through toxicity, potability
		9. Peak storm flow	L/s	Crop choice, % of residue harvested, tillage	Erosion, sediment loading, infiltration
		10. Minimum base flow	L/s	Crop choice, % reside harvested, tillage	Habitat degradation, lack of dissolved oxygen

		11. Consumptive water use (incorporates base flow)	feedstock production: m^3/ha/day; biorefinery: m^3/day	Crop choice, irrigation practices, downstream biomass processing	Availability of water for other uses
Greenhouse gases	**Regulating services:** carbon sequestration and climate regulation	12. CO_2 equivalent emissions (CO_2 and N_2O)	kgC_{eq}/GJ	N fertilizer production and use, crop choice, tillage, liming, fossil fuel use throughout supply chains	Climate change, plant growth
Biodiversity	**Regulating services:** biodiversity, pollination, seed dispersal, pest mitigation; **Supporting service:** habitat	13. Presence of taxa of special concern	Presence	Crop choice, regional land uses, management practices	Biodiversity
		14. Habitat area of taxa of special concern	ha	Crop choice, regional land uses	Biodiversity
Productivity	**Production services:** food, feed, fiber and fuel	15. Aboveground net primary productivity (ANPP) / Yield	gC/m^2/year	Crop choice, management practices	Climate change, soil fertility, cycling of carbon and other nutrients

Table 2. List of recommended socioeconomic indicators for bioenergy sustainability (based on Dale et al. 2015) and associated ecosystem service.

Socioeconomic sustainability category	**Ecosystem service category:** type	**Indicator**	**Units**	**Potential related conditions**
Social well-being	**Cultural services:** jobs and family income; **Provisioning service**: food	Employment	Number of full time equivalent (FTE) jobs	Hiring of local people; rural development; capacity building; food security
		Household income	Dollars per day	Food security, employment, health, energy security, social acceptance
		Work days lost due to injury	Average number of work days lost per worker per year	Employment conditions, risk of catastrophe, social conditions, education and training
		Food security	Percent change in food price volatility	Household income, employment, energy security
Energy security	**Provisioning service:** energy	Energy security premium	Dollars per gallon of biofuel	Crop failures, oil or bioenergy price shocks; macroeconomic losses; shifts in policy, geo-politics or cartel behavior; exposure to import costs; new discoveries and technologies affecting stock/demand ratio
		Fuel price volatility	Standard deviation of monthly percent price changes over one year	
External trade	**Provisioning services**: food, feed, fuel and fiber	Terms of trade	Ratio (price of exports / price of imports)	Energy security, profitability
		Trade volume	Dollars (net exports or balance of payments)	Energy security, profitability
Profitability	**Provisioning services**: food, feed, fuel and fiber	Return on investment (ROI)	Percent (net investment / initial investment)	Soil properties and management practices; sustainability certification requirements; global market prices, terms of trade
		Net present value (NPV)	Dollars (present value of benefits minus present value of costs)	
Resource conservation	**Provisioning services:** fuel, chemicals, plastics	Depletion of non-renewable energy resources	Amount of petroleum extracted per year (MT)	Total stocks maintained; other critical resources depleted and monitored depending on context (e.g. water, forest, ecosystem services)

		Fossil Energy Return on Investment (fossil EROI)	Ratio of amount of fossil energy inputs to amount of useful energy output (MJ) (adjusted for energy quality)	Petroleum share of fossil energy; imported share of fossil energy; energy quality factors; total petroleum consumed
Social acceptability	**Provisioning services**: food, feed, fuel and fiber	Public opinion	Percent favorable opinion	Aspects of social well being, environment, energy security, equity, trust, work days lost, stakeholder participation and communication, familiarity with technology, catastrophic risk
		Transparency	Percent of indicators for which timely and relevant performance data are reported	Identification of a complete suite of appropriate environmental and socio-economic indicators
		Effective stakeholder participation	Percent of documented responses addressing stakeholder concerns and suggestions, reported on an annual basis[f]	Public concerns and perceptions; responsiveness of decision-makers or project authorities to stakeholders; full suite of environmental and socio-economic indicators
		Risk of catastrophe[g]	Annual probability of catastrophic event	Health, including days lost to injury; environmental conditions

Table 3. Selected responses to query about one big idea in Drake University survey that are pertinent to bioenergy production

What is your one big idea? If you could make one change in Iowa's soil and water conservation policy or suggest one idea you think Iowans should consider, what is it?	**Number of times mentioned out of 81 responses**
No till or tillage plans	7
Cover crops	7
Nutrient management plan or conservation plan	7
Reducing soil erosion / increasing soil conservation	6
Increased monitoring	6
Increased regulation or enhance current regulations	5
Funding of conservation practices	5
Buffer strips	4
Education	3

Figure 1. Map of study area in central Iowa.

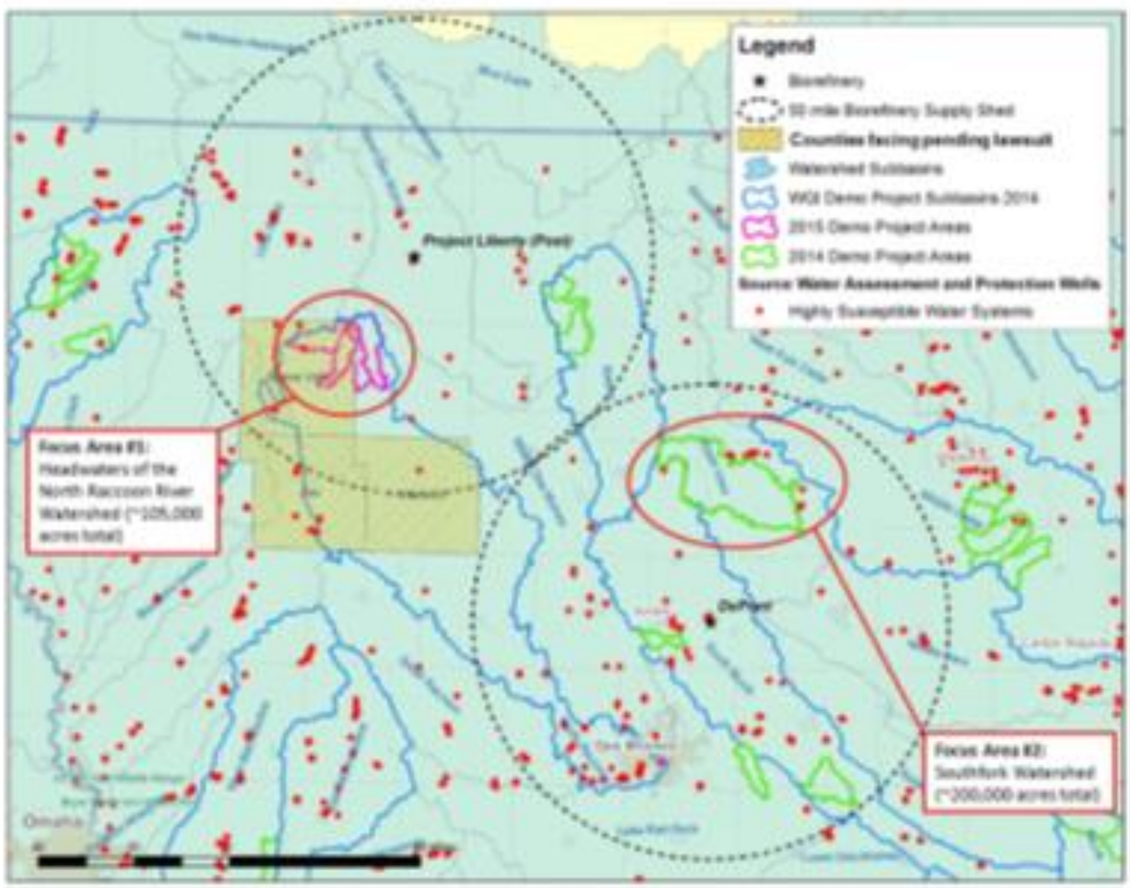


Figure 2. Histogram of selected results from survey conducted by the Drake University Law School at the November 2015 conference on "Sustaining Our Iowa Land (SOIL): Past, Present and Future of Iowa's Soil Water Conservation Policy."

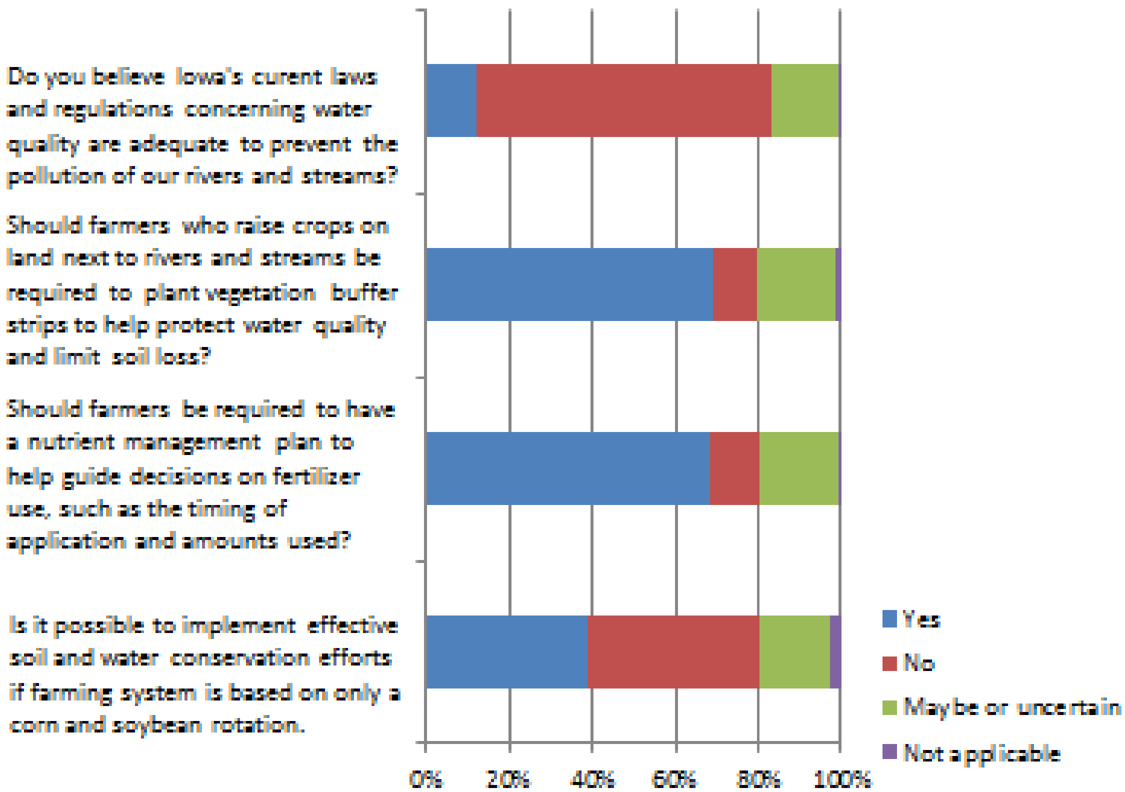
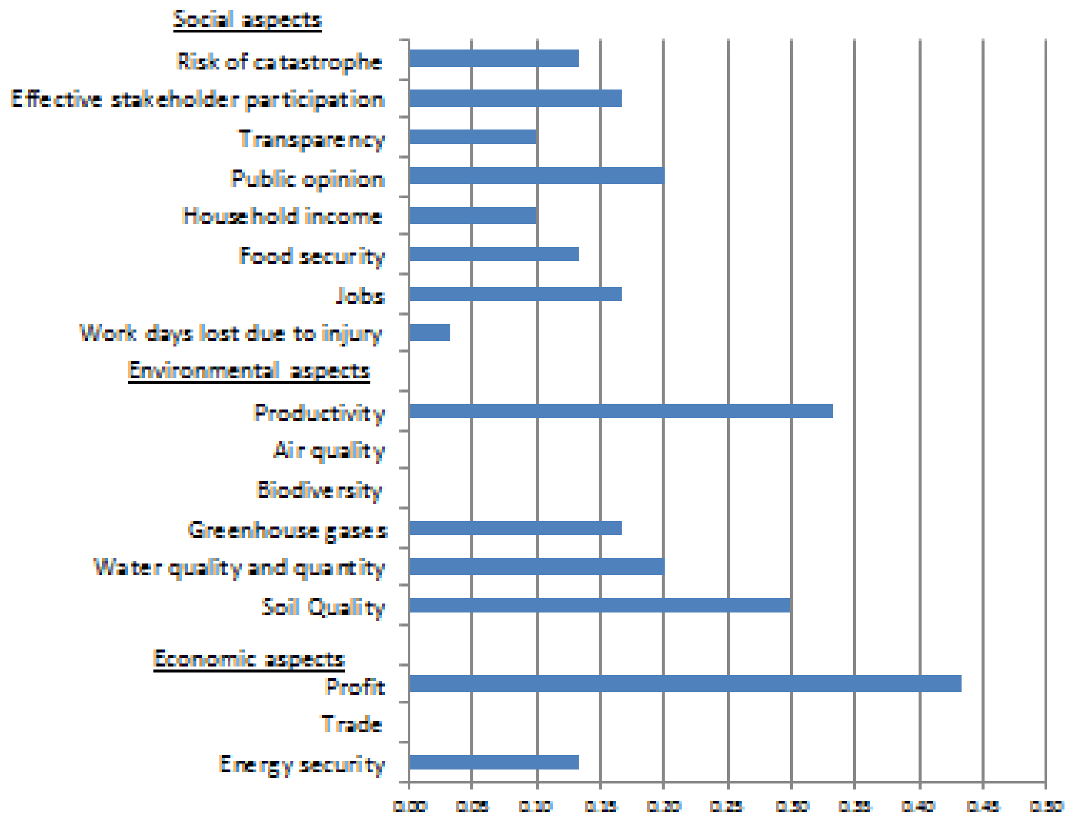


Figure 3. Percent of priority indicators for assessing progress toward bioenergy sustainability that were selected in each of three areas by 30 landscape design meeting participants.



References

[1] Gasparatos A, Lehtonen M, Stromberg P. Do we need a unified appraisal framework to synthesize biofuel impacts? Biomass and Bioenergy, 2013; 50: 75-80, DOI: 10.1016/j.biombioe.2012.09.052

[2] Gasparatos A, Stromberg P, Takeuchi K. Biofuels, ecosystem services and human wellbeing: Putting biofuels in the ecosystem services narrative. Agricultural Ecosystems & Environment, 2011; 142: 111-128. DOI: 10.1016/j.agee.2011.04.020

[3] Kline KL, Msangi S, Dale VH, Woods J, Souza G, Osseweijer P, Clancy J, Hilbert J, Johnson F, McDonnell P, Mugera H. Reconciling food security and bioenergy: priorities for action. GCB-Bioenergy, in press.

[4] Karlen DL, Beeler LW, Ong RG, Dale BE. Balancing energy, conservation, and soil health requirements for plant biomass. Journal of Soil & Water Conservation, 2015;70:279-287.

[5] Kline KL, Dale VH, Lee R, Leiby P. In Defense of Biofuels, Done Right. Issues in Science and Technology, 2009, 25(3): 75-84.

[6] Dale B, Anderson J, Brown R, Csonka S, Dale VH, Herwick G, Jackson R, Jordan N, Kaffka S, Kline K, Lynd L, Malmstrom C, Ong R, Richard T, Taylor C, Wang M. Take a Closer Look: Biofuels Can Support Environmental, Economic and Social Goals. Environmental Science & Technology, 2014; 48:7200-7203.

[7] Robertson, GP, Dale VH, Doering OC, Hamburg SP, Melillo JM, Wander MM, Parton WJ, Adler PR, Barney JN, Cruse RM, Duke CS, Fearnside PM, Follett RF, Gibbs HK, Goldemberg J, Mladenoff DJ, Ojima D, Palmer MW, Sharpley A, Wallace L, Weathers KC, Wiens JA, Wilhelm WW. Sustainable Biofuels Redux, Science 2008; 322(5898): 49–50. DOI: 10.1126/science.1161525.

[8] Souza GM, Victoria RL, Joly CA, Verdade L (eds.) Bioenergy and Sustainability: Bridging the Gaps. SCOPE, 2015; 72 Paris, France

[9] Efroymson RA, Dale VH, Kline KL, McBride AC, Bielicki JM, Smith RL, Parish ES, Schweizer PE, Shaw DM. Environmental indicators of biofuel sustainability: What about context? Environmental Management 2013; 51:291-306.

[10] Rossi AM, Hinrichs CC. Hope and skepticism: Farmer and local community views on the socio-economic benefits of agricultural bioenergy. Biomass Bioenergy 2011; 35:1418-1428.

[11] Dale VH, Kline KL, Buford MA, Volk TA, Smith CT, Stupak I. Incorporating bioenergy into sustainable landscape designs. Renewable & Sustainable Energy Reviews 2016; 56:1158-1171.

[12] Becher KD, Kalkhoff SJ, Schnoebelen DJ, Barnes KK, Miller VE. Water-quality assessment of the Eastern Iowa Basins—nitrogen, phosphorus, suspended sediment, and organic carbon in surface water, 1996–98: U.S. Geological Survey Water-Resources Investigation Report 01–4175, 2001; 56 p.

[13] Libra RD, Wolter CF, Langel RJ. Nitrogen and phosphorus budgets for Iowa and Iowa watersheds. Technical Information Series 47. Iowa Department of Natural Resources Geological Survey, Iowa City, Iowa, 2004. http://www.iowadnr.gov/portals/idnr/uploads/water/standards/nbfull.pdf [accessed 22 April 2016].

[14] Jha MK, Wolter CF, Schilling KE, Gassman PW. Assessment of total maximum daily load implementation strategies for nitrate impairment of the Raccoon River, Iowa. Journal of Environmental Quality, 2010; 39: 1317-1327. Doi: 10.2134/jeq2009.0392.

[15] Hatfield JL, McMullen LD, Jones CS. Nitrate-nitrogen patterns in the Racoon River Basin related to agricultural practices. Journal of Soil and Water Conservation, 2009; 64(3):190-199. Doi: 10.2489/jswc.64.3190.

[16] Dale VH, Kling C, Meyer JL, Sanders J, Stallworth H, Armitage T, Wangsness D, Bianchi TS, Blumberg A, Boynton W, Conley DJ, Crumpton W, David MD, Gilbert D, Howarth RW, Lowrance R, Mankin K, Opaluch J, Paerl H, Reckhow K, Sharpley JN, Simpson TW, Snyder C, Wright D. Hypoxia in the Northern Gulf of Mexico. 2010;New York: Springer.

[17] Alexander RB, Smith RA, Schwarz GE, Boyer EW, Nolan JV, Brakebill JW. Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi River Basin. Environmental Science & Technology, 2009; 42:822-830.

[18] Hatfield JL, McMlullen LD, Jones CS. Nitrate-nitrogen patterns in the Racccoon River Basin related to agricultural practices. Journal of Soil and Water Conservation, 2009; 66(3):q190-199.

[19] Iowa Nutrient Reduction Stategy. Iowa State University, 2015. http://www.nutrientstrategy.iastate.edu/documents [accessed 22 April 2016].

[20] http://www.dmww.com/upl/documents/about-us/announcements/notice-of-intent-to-sue.pdf [Accessed 22 April 2016].

[21] Zhou X, Helmers MJ, Asbjornsen H, Kolka RK, Tolmer MD, Cruz RM. Nutrient removal by prairie filter strips in agricultural landscapes. Journal of Soil and Water Conservation, 2014, 69(1):54:64. doi:10.2489/jswc.69.1.54

[22] Torjai LT, Nagy J, Bai A. Decision hierarchy, competitive priorities and indicators in large-scale 'herbaceous biomass to energy' supply chains. Biomass Bioenergy 2015; 80:321-329.

[23] Thompson JL, Tyner WE. Corn stover for bioenergy production: Cost estimates and farmer supply response. Biomass Bioenergy 2014; 62:166-173.

[24] Junginger M, van Dam J, Zarrilli S, Mohamed FA, Marchal D, Faaij A. Opportunities and barriers for international bioenergy trade. Energy Policy 2011; 39:2028-2042.

[25] McBride, A, Dale VH, Baskaran L, Downing M, Eaton L, Efroymson RA, Garten C, Kline KL, Jager H, Mulholland P, Parish E, Schweizer P, Storey J. Indicators to support environmental sustainability of bioenergy systems. Ecological Indicators 2011;11:1277-1289.

[26] Dale VH, Efroymson RA, Kline KL, Langholtz MH, Leiby PN, Oladosu GA, Davis MR, Downing ME, Hilliard MR. Indicators for assessing socioeconomic sustainability of bioenergy systems: A short list of practical measures. Ecological Indicators 2013;26:87-102 http://dx.doi.org/10.1016/j.ecolind.2012.10.014

[27] Dale VH, Efroymson RA, Kline Kl, Davitt M. A framework for selecting indicators of bioenergy sustainability. Biofuels, Bioproducts & Biorefining 2015; 9: 435-446. DOI: 10.1002/bbb.1562

[28] Agenda for conference on "Sustaining Our Iowa Land (SOIL): Past, Present and Future of Iowa's Soil Water Conservation Policy" at Drake University Law School in Des Moines, Iowa, Nov 19-20. 2015. http://drakeaglaw.org/conference-follow-up/

[29] Survey responses http://drakeaglaw.org/wp-content/uploads/2015/11/Survey-results-pre-SOIL-conference.pdf

[30] http://www.capitalcrossroadsvision.com/

[31] Hamilton LC, Hamilton LR, Duncan C, Colocousis C. Place matters: challenges and opportunities in four rural Americas. No. 4. In: Reports on rural America, vol. 1. Durham, NH: Carsey Institute, University of New Hampshire, http://www.carseyinstitute.unh.edu/publications/Report_PlaceMatters.pdf; 2008 [accessed 22 April 2016]

[32] Caldas MM, Bergtold JS, Peterson JM, Graves RW, Earnhart D, Gong S, Lauer B, Brown JC. Factors affecting farmers' willingness to grow alternative biofuel feedstocks across Kansas. Biomass Bionergy 2014; 66:223-231.

[33] Karlen DL, Birrell SJ, Johnson JMF, Osborne SL, Schumacher TE, Varvel GE, Ferguson RB, Novak JM, Fredrick JR, Baker JM, Lamb JA, Adler PR, Roth GW, Nafziger ED. Multilocation corn stover harvest effects on crop yields and nutrient removal. BioEnergy Research, 2014; 7:528-539.

[34] Karlen DL, Kovar JL, Birrell SJ. Corn stover nutrient removal estimates for central Iowa, USA. Sustainability, 2015; 7:8621-8634.

[35] Mourtzinis S, Cantrell K, Arriaga F, Balkcom K, Novak J, Frederick J, Karlen DL. Distribution of structural carbohydrates in corn plants across the southeastern USA. Bioenergy Research, 2014; 7:551-558.

[36] Cantrell KB, Novak JM, Frederick JR, Karlen DL, Watts DW. Influence of corn residue harvest management on grain, stover, and energy yields on Coastal Plain toposequential soils. BioEnergy Research, 2014, 7:590-597.

[37] Emerson R, Hoover A, Ray A, Lacey J, Cortez M, Payne C, Karlen DL, Birrell S, Laird D, Kallenbach R, Egenolf J, Sousek M, Voigt T. Drought effects on composition and yield for corn stover, mixed grasses, and Miscanthus as bioenergy feedstocks. Biofuels, 2014; 5(3): 275-291.

[38] Johnson JMF, Karlen DL, Gresham GL, Cantrell KB, Archer DW, Wienhold BJ, Varvel GE, Laird DA, Baker JM, Ochsner TE, Emerson R, Barbour NW. Vertical distribution of structural component in corn stover. Agriculture, 2014; 4:274-287. doi:10.3390/agriculture4049274.

[39] Karlen DL, Varvel GE, Johnson JMF, Baker JM, Osborne SL, Novak JM, Adler PR, Roth GW, Birrell SJ. Monitoring soil quality to assess the sustainability of harvesting corn stover. Agronomy Journal, 2011; 103:288–295.

[40] Johnson JMF, Novak JM, Varvel GE, Stott DE, Osborne SL, Karlen DL, Lamb JA, Baker J, Adler PR. Crop residue mass needed to maintain soil organic carbon levels: Can it be determined? BioEnergy Research, 2014, 7:481-490.

[41] Benjamin JG, Karlen DL. LLWR techniques for quantifying potential soil compaction consequences of crop residue removal. BioEnergy Research, 2014, 7:468-480.

[42] Gan J, Langeveld JWA, Smith CT. An agent-based modeling approach for determining corn stover removal rate and transboundary effects. Environmental Management 2013; XXX
[43] Karlen DL, Birell SJ, Hess JR. A five-year assessment of corn stover harvest in central Iowa, USA. Soil & Tillage Research 2011; 115-116:47-55.
[44] Wu Y, Liu S. Impacts of biofuels production alternatives on water quantity and quality in the Iowa River Basin. Biomass Bioenergy 2011;36:182-191.
[45] Hill J, Polasky S, Nelson E, Tilman D, Huo H, Ludwig L, Neumann J, Zheng HC, Bonta D. Climate change and health costs of air emissions from biofuels and gasoline. Proceedings of the national Academy of Sciences of the United States of America 2009;106:2077-2082.
[46] Atwell RC, Schulte LA, Westphal LM. Landscape, community, countryside: linking biophysical and social scales in US Corn Belt agricultural landscapes. Landscape Ecology 2009;24(6):791-806.
[47] Prochnow A, Heiermann M, Plochl M, Amon T, Hobbs PJ. Bioenergy from permanent grassland - A review: 2. Combustion. Bioresource Technology 2009; 100(21):4945-4954.
[48] Myers MC, Hoksch BJ, Mason JT. Butterfly response to floral resources during early establishment at a heterogeneous prairie biomass production site in Iowa, USA. Journal of Insect Conservation. 2012;16:457-472.
[49] Bonner IJ, Cafferty KG, Muth DJ, Tomer MD, James DE, Porter SA, Karlen DL. Opportunities for Energy Crop Production Based on Subfield Scale Distribution of Profitability. Energies 2014;7:6509-6526.
[50] Nichols VA, Miguez FE, Jarchow ME, Liebman MZ, Dien BS. Comparison of Cellulosic Ethanol Yields from Midwestern Maize and Reconstructed Tallgrass Prairie Systems Managed for Bioenergy. Bioenergy Research 2014;7:1550-1560.
[51] Myers MC, Mason JT, Hoksch BJ, Cambardella CA, Pfrimmer JD. Birds and butterflies respond to soil-induced habitat heterogeneity in experimental plantings of tallgrass prairie species managed as agroenergy crops in Iowa, USA. Journal of Applied Ecology 2015;52:1176-1187.
[52] Murphy CW, Parker NC. Impact of air pollution control costs on the cost and spatial arrangement of cellulosic biofuel production in the US. Environmental Science & Technology 2014;48:2157-2164.
[53] Zhang Y, Heath G, Carpenter A, Fisher N. Air pollutant emissions inventory of large-scale production of selected biofuels feedstocks in 2022. Biofuels, Bioproducts and Biorefining, 2016; 10:56-69. doi:10.1002/bbb.1620.
[54] Tessum CW, Hill JD, Marshall JD. Life cycle air quality impacts of conventional and alternative light-duty transportation in the United States. Proceedings of the National Academy of Sciences, 2014; 111(52):18490-18495.
[55] Tyndall JC, Berg EJ, Colletti JP. Corn stover as a biofuel feedstock in Iowa's bio-economy:
An Iowa farmer survey. Biomass Bioenergy 2011;35: 1485-1495.
[56] Altman I, Sanders D. Producer willingness and ability to supply biomass: Evidence from the U.S. Midwest. Biomass Bioenergy 2012; 36:176-181.
[57] Paulrud S, Laitila T. Farmers' attitudes about growing energy crops: a choice experiment approach. Biomass Bioenergy 2010;34:1770e9.