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Research paper

Biomass and biofuel crop effects on biodiversity and ecosystem services in the North Central US

Douglas A. Landis [a, b, *], Claudio Gratton [c, d], Randall D. Jackson [d, e], Katherine L. Gross [b, f], David S. Duncan [d, e], Chao Liang [d, g, 1], Timothy D. Meehan [c, d, 2], Bruce A. Robertson [a, b, 3], Thomas M. Schmidt [b, h, 4], Karen A. Stahlheber [d, f, 5], James M. Tiedje [b, i], Benjamin P. Werling [a, b, 6]

[a] Department of Entomology, Michigan State University, East Lansing, MI, USA
[b] DOE Great Lakes Bioenergy Research Center, Michigan State University, USA
[c] Department of Entomology, University of Wisconsin-Madison, Madison, WI, USA
[d] DOE Great Lakes Bioenergy Research Center, University of Wisconsin-Madison, USA
[e] Department of Agronomy, University of Wisconsin-Madison, Madison, WI, USA
[f] W.K. Kellogg Biological Station & Plant Biology Department, Michigan State University, Hickory Corners, MI, USA
[g] Department of Soil Science, University of Wisconsin-Madison, WI, USA
[h] Department of Microbiology & Molecular Genetics, Michigan State University, East Lansing, MI, USA
[i] Center for Microbial Ecology, Michigan State University, East Lansing, MI, USA

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A B S T R A C T

Biomass cropping systems have the potential to alter the ecosystem services provided by agricultural landscapes. Depending on crop type and management, strategic incorporation of biomass cropping systems into existing agricultural landscapes could enhance a range of ecosystem services while mitigating some disservices. Here, we review the approaches and findings of eight years of research into the potential effects of a range of biomass cropping systems on ecosystem services in the North Central US. Our research was framed by an initial assessment of the abundance and distribution of multiple taxa (i.e., biodiversity) within candidate biomass cropping systems. The processes underpinning important ecosystem services in each system were then measured or modeled, related to biodiversity metrics, and used to explore the influence of management scenarios on biodiversity and ecosystem processes. We also used these data and models to develop a decision support system that allows stakeholders to consider tradeoffs and synergies under alternative landscape composition, configuration, and agronomic management. Perennial grass cropping systems provided the greatest potential to promote multiple ecosystem services. More diverse perennial grasslands that include forbs have the potential to increase pest suppression and pollination, decrease greenhouse gas emissions, and enhance grassland bird communities, but likely at the expense of biomass yield. Providing stakeholders and policymakers with information about the expected mix of ecosystem services supported by different biomass feedstock cropping systems in advance of their adoption offers the potential for informed choices to guide the implementation and management of future biomass-producing landscapes.

* Corresponding author. Department of Entomology, Michigan State University, East Lansing, MI, USA.
E-mail address: landisd@msu.edu (D.A. Landis).

[1] Present address, Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China.
[2] Present address, Science Division, National Audubon Society, Boulder, CO, USA.
[3] Present address, Division of Science, Mathematics & Computing, Bard College, Annandale-on-Hudson, NY, USA.
[4] Present address, Department of Ecology & Evolutionary Biology, University of Michigan, Ann Arbor, MI, USA.
[5] Present address, Natural and Applied Sciences, University of Wisconsin Green Bay, Green Bay, WI, USA.
[6] Present address, MSU Extension, Hart, MI, USA.

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1. Introduction

The adoption of biomass cropping systems to supply feedstocks to bioenergy and bioproducts industries has the potential to alter the mix of ecosystem services realized from agricultural landscapes [1]. In the North Central US, current biomass cropping systems are primarily monocultures of the annual crops corn and soybean. However, the diversity of systems used for biomass crops in the region is likely to be augmented in the future by dedicated crops based on perennial plants [2]. Assessing what biomass crops to grow, where to grow them, and how they should be managed represents a complex combination of socio-political, economic, and ecological decisions that will determine the mix of ecosystem services we derive from agricultural lands.

An ecosystem services framework has been useful in evaluating the relative merits of different bioenergy production systems. Gasparatos et al. [1] reviewed the impact of first-generation biofuel production systems on biodiversity, and resulting provisioning, regulating and cultural services. They found that while some provisioning (fuel) and regulating services (climate regulation) may be enhanced, this often comes at the expense of biodiversity, and other provisioning (food, water) and regulating (air quality, erosion control) services. Joly et al. [3] also used an ecosystem services framework to examine the impacts of biofuel production systems on biodiversity and ecosystem services. They conclude that the land transformations that have taken place globally to produce biofuels have resulted in serious biodiversity declines. However, they also conclude that the effects of biofuel production on ecosystem services is highly context and location-specific, with some systems having the potential to enhance ecosystem services. Indeed, a recent synthesis examining the impacts of second-generation bioenergy cropping systems in Europe suggest that transitioning from first-generation feedstocks to dedicated lignocellulosic feedstocks may frequently improve ecosystem services [4].

The development of biomass crops has been underway in the US since the 1970s, with significant crop improvement efforts conducted under the auspices of the US Department of Energy (US DOE) [5]. In the mid-2000s, the desire to reduce dependence on foreign sources of oil and the environmental load of fossil fuel combustion, coupled with advances in the potential to derive transportation fuels from cellulosic biomass, fostered a resurgence of research into biomass cropping systems. During this time, there was also a growing consensus that a focused national effort was needed to enable the emergence of a cellulosic biofuel industry. In 2006, the US DOE Office of Science and the Office of Energy Efficiency and Renewable Energy released a report that outlined a 15-year strategy of research, technology development, and systems integration aimed at supporting a cellulosic biofuels sector [6]. This report was seen as the original research roadmap supporting the formation of three national Bioenergy Research Centers charged with providing the fundamental science to underpin an environmentally sustainable and economically competitive advanced cellulosic biofuels industry. In 2007, the Great Lakes Bioenergy Research Center (GLBRC) was one of three national research centers funded by the US DOE to pursue this mission [7,8].

Corn and soybean have long dominated the agricultural landscape of the North Central US. In recent years, 35–40% of the US corn crop has been used to produce ethanol that is blended into Nitrogen and phosphorous typically are added to these cropping systems to maintain productivity and manage livestock manure. These inputs, particularly when combined with tillage can result in excessive leaching of nitrogen to ground- and surface-waters and to overland movement of phosphorous attached to soil particles to surface waters [9] resulting in local to continental eutrophication of water bodies [10]. Also, significant amounts of the nitrogen added as inorganic fertilizer can be lost via volatilization or microbe-mediated nitrification and dentirification [11,12], contributing to ecosystem disservices that include excessive deposition locally and accumulation of greenhouse gases globally. Largely because of high inputs, the net energy gain of developing biofuels from annual crops appears to converge near zero [13]. Increasing production of annual crops through intensification on existing crop land or conversion of marginal lands [14] threatens other ecosystem services important to the sustainability of agricultural landscapes e.g. natural pest suppression [15].

Concerns about the sustainability of current biofuel cropping systems prompted research to derive fuels and other bioproducts from cellulosic biomass sourced from dedicated energy crops and/or food crop residues [16,17]. However, harvesting residues of annual crops does not address the environmental concerns stated above, and could exacerbate these problems by driving the planting of even more land to annual crops. Alternatively, the addition of dedicated cellulosic crops significantly broadens the options for potential feedstock producing cropping systems, providing opportunities for coupling ecosystem service improvements and ecologically sustainable production [18]. Perennial plants such as native prairies grasses, tropical grasses, and short rotation trees show promise as sustainable biomass crops because they minimize erosion by covering the soil year-round and minimize energy costs of agronomic management stemming from fossil fuel use for planting equipment and production and application of pesticides and fertilizers [19,20]. However, the benefits of incorporating perennials into current agricultural landscapes as part of a sustainable biomass cropping system has received less research attention (but see Refs. [21,22]). Understanding how perennial biomass cropping systems – specifically those planted with native species – could be integrated into North Central US cropping systems to enhance multiple ecosystem services has been a focus of the GLBRC Biodiversity Team.

Here, we review more than 35 studies conducted by the GLBRC Biodiversity Team, where we compared the potential effects of alternative biomass cropping systems on the organisms and processes that provide important supporting, provisioning, regulating and cultural services in agricultural landscapes. The following central questions directed our research: 1) How does the choice of biomass crop(s) influence biodiversity and the potential to provide ecosystem services that can be delivered at the level of a crop field and to the overall landscape? 2) How do different management practices affect the ecosystem services provided by alternative systems?, and 3) How does the configuration of biomass and other crops in an agricultural landscape influence ecosystem services provided to other crops? Our hypothesis was that perennial biomass cropping systems, particularly those with higher plant species diversity, would provide more ecosystem services and reduce associated disservices compared to annual cropping systems. We addressed this hypothesis by estimating how crop yields and other ecosystem services provided by a variety of cellulosic biomass crops differed and how these relationships varied when measured at plot-, field-, and landscape-levels of spatial organization.

2. Materials and methods

Below we provide an overview of methods used in the studies we review. Details about the specific sites and methods used can be found in the individual publications cited (Table 1).

2.1. Sites

Research sites were located in southern Wisconsin and