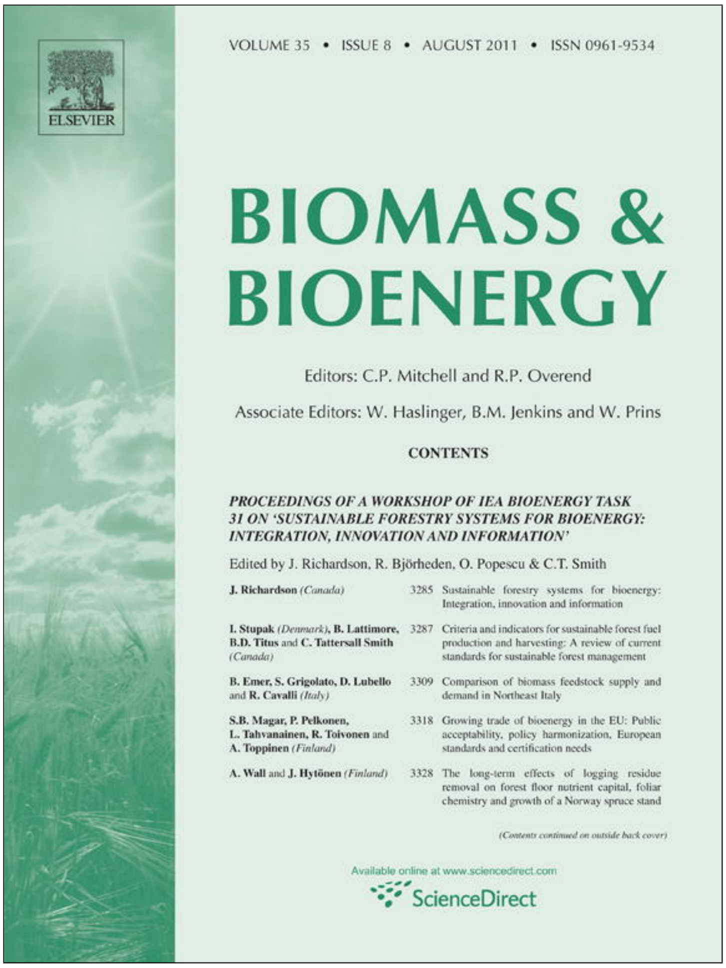
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Review

Potential ecological impacts of switchgrass (*Panicum virgatum* L.) biofuel cultivation in the Central Great Plains, USA

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ABSTRACT

Switchgrass (*Panicum virgatum* L.) is a broadly adapted warm-season grass species native to most of the central and eastern United States. Switchgrass has been identified as a potential biofuel species because it is a native species that requires minimal management, and has a large potential to sequester carbon underground. Since the 1990's, switchgrass has been bred to produce cultivars with increased biomass and feedstock quality. This review addresses potential ecological consequences of widespread switchgrass cultivation for biofuel production in the central United States. Specifically, this review address the ecological implications of changing use of marginal and CRP land, impacts on wildlife, potentials for disease and invasions, and changes in soil quality through reductions in erosion, decomposition rates, and carbon sequestrations. A central theme of the review is the utility of maintaining landscape heterogeneity during switchgrass biofuel production. This includes implementing harvest rotations, no till farming, and mixed species composition. If negative ecological consequences of switchgrass cultivation are minimized, biofuel production using this species has economical and environmental benefits.

1. Introduction

Panicum virgatum L. (switchgrass) is a common perennial C_4 grass that is widely distributed across North America. Ecologically, this species is a dominant plant in the central Great Plains grasslands, with impacts on both the structure and function of these ecosystems [1,2]. Considerable genotypic and phenotypic variability exists for switchgrass [3,4]. This variability contributes to the broad adaptation of this species across a wide geographic and environmental range [5]. For example, switchgrass has a robust distribution across North America, from 5 to 25 °C MAT and 300–1500 mm MAP (Fig. 1). In general, ecotypes of switchgrass are broadly divided into two types: upland and lowland [6]. Upland ecotypes have a smaller size, and lower water and nitrogen requirements than lowland ecotypes [6]. Additionally, upland ecotypes are typically octoploid or hexaploid, whereas lowland ecotypes are tetraploid [6,7].

Practically, switchgrass is an important forage crop in pasture lands, and has been studied extensively over the past two decades for its potential value as an alternative energy source. In recent years, switchgrass has become a model species for biofuel production [8]. Switchgrass was chosen as a prospective biofuel for its ability to increase soil

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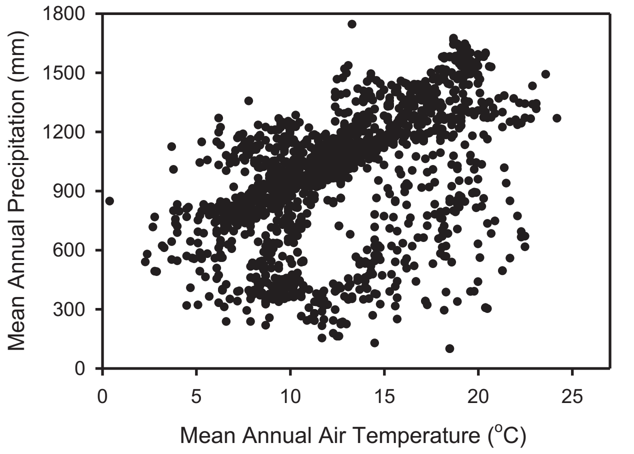

Fig. 1 – Climate distribution of switchgrass in the conterminous United States. Each datapoint represents a natural history collection for *Panicum virgatum* ($n = 1689$) recorded in the Global Biodiversity Information Facility (http://www.gbif.org/). The climate data associated with each collection location was generated by WorldClim – Global Climate Data (http://www.worldclim.org).

quality, sequester carbon, and its wide range of suitable habitat [9]. While the potential economic benefits of implementing switchgrass for biofuel production are enormous, the environmental consequences of cultivation must be considered [10]. Large amounts of land will be required for cultivation, and this land will be transferred from previous agricultural or conservation practices to switchgrass biofuel production [11]. The environmental impacts of changing land-use to biofuel production have yet to be adequately assessed [12]. If switchgrass cultivation for biofuels is to be successfully implemented in the Central Great Plains of the United States, the potential ecological impacts must be assessed in concert with economical impacts.

2. Cultivation in marginal or CRP lands

Marginal lands that are not currently used for agricultural production may be suitable for switchgrass cultivation. The use of marginal lands for biofuel production is desirable because utilization of this land minimizes competition with food crops produced on lands of higher agricultural value [13]. Switchgrass cultivation in marginal lands has great potential value because this species produces high biomass across a broad range of environments, requires low water and nutrient inputs compared to agronomic species (e.g., corn), and provides environmental benefits for degraded lands (e.g., reduced erosion, increased soil organic carbon) [14,15]. The production potential of switchgrass on marginal lands is equal to or greater than other potential herbaceous biofuels like corn [16] and switchgrass cultivation in marginal lands provides wildlife cover while promoting landscape heterogeneity and biodiversity compared to conventional corn-grain production [12,17]. However, the positive biodiversity and landscape heterogeneity benefits of switchgrass cultivation or other perennial herbaceous energy crops for biofuels are minimized when grown in monoculture [12].

The cultivation of switchgrass as a perennial energy crop has also been considered for marginal lands currently in the Conservation Reserve Program (CRP). This program, developed in 1985 as part of the Food Security Act, provides compensation for landowners to rest their land from continual agricultural production. A byproduct of removing the land from agricultural production is the establishment of permanent grass cover. As of 2008, there were 34.7 million acres enrolled in the Conservation Reserve Program [18]. The CRP program has successfully advanced conservation practices, with estimated decreases in soil erosion of 220 million tons/year, and native bird populations have increased by 2–52% [19,20]. The 2008 Farm Bill allowed for 32 million acres to be enrolled, so a large amount of land was not renewed, and is available for switchgrass cultivation [18]. While CRP lands can be cultivated, the economic value for food production is often considerably lower. Some scenarios for switchgrass cultivation on CRP lands have been estimated at 3.3 to 5.2 million hectares of CRP land being converted [21]. Within the Central Great Plains region, a large amount of agricultural land is enrolled as CRP land (Fig. 2). Those lands to be converted would not include CRP land that is used as buffer zones, wetlands, or critical habitats [21].

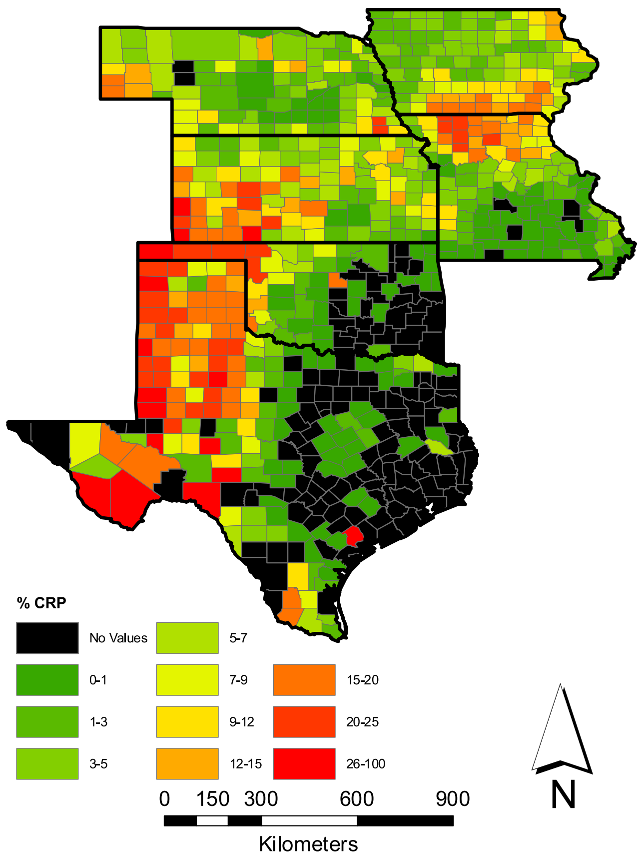

Fig. 2 – Distribution of Conservation Reserve Program (CRP) land in the Central Great Plains. Total CRP land amounted to 11.1 million acres (4.5 million ha). For each county, percent CRP lands were derived from total croplands. Data source from the Farm Service Agency (http://content.fsa.usda.gov/crpstorpt/rmepeii_r1/r1mepeii.htm).

Thus, switchgrass cultivation would not be appropriate in all CRP lands, and more research is necessary to assess the biodiversity and wildlife habitat consequences of converting some CRP lands to biofuel production. Ultimately, the applicability of using marginal lands or CRP lands for switchgrass production requires effective harvesting techniques that maximize yield while minimizing land degradation and impacts on native plants and wildlife. To manage the trade off between productivity, long-term sustainability and habitat heterogeneity, a proportion of converted CRP land would likely need to remain unharvested in the establishment year. Schmer and colleagues estimated that switchgrass on CRP land requires 40% stand establishment of the initial switchgrass planting, for subsequent annual harvests [22]. However, these authors estimate 25% stand establishment is sufficient if the stand is harvested every few years [22].

3. Potential for disease, insect outbreaks, & invasive species

Historically, biofuel production has been planned and implemented similar to production agriculture, in monoculture ecosystems [23]. This technique is advantageous because monocultures are selected and cultivated for species and populations with the highest yield [23]. However, monoculture production can have negative ecological consequences. For example, biofuel crops selected for high productivity have increased vulnerability to plant pathogens and pests due to decreases in genetic diversity and heterogeneity [23,24]. For switchgrass in particular, increased susceptibility to some strains of the yellow barley dwarf virus occurs when grown in large monocultures [5]. Monocultures accelerate the spread of pests and pathogens because the suitable host has high abundance and distribution across the landscape. For switchgrass, pests and pathogens include insects, fungi, water molds, bacteria, mollicutes, protozoa, nematodes, and viruses. In 2009, Crouch and colleagues identified a new fungal species, *Colletotrichum navitas*, which is the cause of switchgrass anthracnose [25]. Previously, anthracnose had been thought to be caused by a different fungal species, *Colletotrichum graminacola*, *C. navitas* displayed many characteristics of close relatives such as decreased plant vigor which led to necrotic tissue eventually covering much of the plants affected. However, *C. navitas* also displayed a few unique traits such as host association and many fixed molecular characters [25]. These pests and pathogens can negatively impact switchgrass in numerous ways, including physical and physiological damage through excessive herbivory [24]. Herbivory can result in reduced physiological functioning via toxin production which reduces cellular physiological functioning and ultimately leads to cell death of the infected tissue [24]. The fall armyworm, *Spodoptera frugiperda* has been shown capable of developing on switchgrass. In laboratory tests, the larval form showed a strong preference for feeding on the leaf tissues of young switchgrass stands [26]. These physical and physiological impacts reduce photosynthetic rates and ultimately decrease biomass production. Therefore, it is vitally important to understand the interactions between host and pathogen and minimize the potential for disease or insect outbreaks by using diverse genotypes or multi-species assemblages within the area cultivated for biofuel production.

Another negative trade off associated with monocultures is the punctuated seasonal tempo of growth and productivity, leaving large periods of time with gaps in standing biomass. Fluctuations in insect diversity and abundance mimic these fluctuations in productivity [23]. Productivity gaps affect the plant–herbivore interactions within the monoculture [23]. Changing the interaction between predators and prey has the potential to enhance the vulnerability of biofuels such as switchgrass especially if genetic diversity within the population is low. While the topic of disease potential in biofuel monocultures has been discussed initially, this is a topic requiring considerable future research, with a specific studies focused on key biofuel species, including switchgrass [25]. Specifically, outbreaks, spread, and consequences of the pests, pathogens, and diseases on monoculture switchgrass cultivation remain to be evaluated.

Pathogens and pests have the potential to negatively impact establishment, biomass productivity, and stand survival in perennial herbaceous crops grown for biofuels [24]. The impacts of rust fungi on switchgrass have been assessed in several studies. In 1941, Cornelius and Johnston [27] examined 34 accessions of switchgrass from South Dakota, Nebraska, Oklahoma, and Texas and found that collections from South Dakota and Nebraska were more susceptible to the rust *Uromyces graminicola*, than those from Oklahoma and Texas. In 1967, Barnett and Carver [28] reported lowland ecotypes were more rust resistant than upland ecotypes due to coarser stems. Moreover, Gustafson and colleagues examined the impacts of another rust species, *Puccinia emaculata* [29]. Their results showed variation within and among populations of switchgrass at two different sites in South Dakota. These results suggest selection of cultivars for biomass production should consider populations with appropriate pest resistance as well as appropriate environmental tolerance (e.g., winter hardy) [29].

Monocultures of switchgrass and other biofuel crops increase the potential for future invasion of non-native species. Reduced landscape heterogeneity increases the susceptibility of an area to new invasive species [23,24]. Simberloff in 2008 [30] states that many invasive species remain restricted or dormant for decades until such a time when environmental conditions change in favor of their growth and subsequent spread. The potential for the release from environmental restriction for invasive species increases as more land is allocated to monoculture biofuel production. Additionally, many of the species chosen for biofuel cultivation share similar characteristics with invasive species including phenological characteristics such as perennial lifespans and rapid spring growth, as well as physiological characteristics such as the C_4 photosynthetic pathway and high water-use efficiency [31]. These types of potential biofuel species may be candidate species for undesirable spread from their natural or agricultural areas. For example, native species have the potential to become invasive as grazing or fire suppression is increased [30], or as climate change expands the potential habitat of the species [11]. The invasive risk from biofuel species can also increase as different genotypes are engineered and introduced across the landscape. For switchgrass, this threat is already eminent and worthy of future consideration.

Barney and DiTomaso (2008) [32] relate the extensive bioengineering of switchgrass cultivars and varieties to invasion potential in introduced regions in California and the Pacific Northwest, where switchgrass cultivation trials with engineered genotypes are currently being conducted. Although their evaluations concluded switchgrass was not likely to become an extensive invader under current climate conditions, an altered future climate could shift the invasive capability of switchgrass in these regions. This potential invasive capability under climatic changes needs to be studied experimentally in the future.

4. Impacts on wildlife

Switchgrass cultivation in marginal farming lands and CRP land can provide needed habitat for bird and insect populations if landscape heterogeneity is maintained via mixed species assemblages and rotational harvests [33]. By retaining the structural (grassy) composition of CRP land or marginal land when converted to biofuel production, native grassland wildlife species are supported by a habitat more closely resembling their native grassland communities [34]. The maintenance of vertical and horizontal habitat structure supports multiple ecological niches for insect, bird, reptile and mammal populations [35]. One way to decrease the impact on wildlife biodiversity would be through crop rotation. Milder et al. (2008) [35] suggested that short rotations with both perennial grass and fast-growing woody species would maintain biodiversity. McCoy and colleagues (2001) [36] suggested CRP land-conversion should focus on a combination of warm and cool season grasses to maximize the potential benefits to wildlife rather than single species plantings of warm-season grasses, such as switchgrass. This strategy provides wildlife populations a shifting mosaic of available habitats. Semere and Slater (2007) [37] showed that the diversity of invertebrates increase indirectly through the abundance of mixed species composition within biomass crop fields. The consequence of reduced landscape heterogeneity and viable habitat is reduced wildlife biodiversity.

Appropriate harvest rotations have the potential to increase the stability of grassland bird populations [37–39]. When switchgrass was cultivated in CRP land in Iowa, nest cover was available early in the year, reducing the impact of harvests that occur later in the fall [38]. As long as the CRP fields were a mix of harvested and non-harvested fields, stable breeding habitat would still be available for those species that breed later in the year. For example, fields not harvested in the fall provide much needed over-wintering cover and forage sites for bird species that feed on invertebrates and seeds [37]. Similarly, when CRP land is converted to switchgrass cultivation, the diversity of local grassland bird populations increases only when there is a mixture of harvested and unharvested fields. Harvested fields showed increased diversity in shortgrass bird species, while unharvested fields increased in tallgrass bird species diversity [40]. To date, most research has been conducted over the short-term, so further monitoring of bird populations and assessments of habitat availability and suitability must be continued as more land is converted to switchgrass production [41–43].

5. Changes in soil quality

5.1. *Soil type*

The broad distribution of suitable habitat for switchgrass in the United States spans a range of soil types. The direct impacts of soil type on switchgrass productivity may be less than other grasses [44]. Soil type effects on distribution are likely indirectly related via rainfall patterns. Evers and Parsons (2003) [45] report that rainfall every 7–10 days is required for switchgrass to survive in sandy soils, but less frequent rainfall is required in clay soils. Therefore, climate is likely to exert a greater influence on switchgrass survival and productivity across suitable habitat, rather than differences in soil type. Switchgrass is tolerant of both extreme soil moisture conditions for short periods of time, from flooded soils to low levels of soil moisture [46]. This broad soil moisture tolerance is a direct contributor to the broad habitat distribution in the United States for flooded and drought conditions. Future predictions for suitable switchgrass habitat include most of the eastern and midwestern regions of the United States, with habitat boundaries shifting northward toward the end of the century as the average air temperature increases [11].

5.2. *Decomposition*

Rates of decomposition affect soil quality, driven largely by changes in precipitation, temperature, soil factors, and litter quality [47]. For the Great Plains region, annual precipitation is predicted to increase slightly over the next century with a greater increase in annual temperature [48]. The impact of high temperature to increase decomposition rates is present only when precipitation is not limiting. Since precipitation is limiting grassland productivity across most of this region [49], increased temperature would decrease root decomposition, and therefore increase the carbon storage of grasslands [50]. Another component of decomposition is the litter quality, which is affected by the allocation of nutrients by the plant. Plants that allocate large amounts of carbon to structural components, like lignin, generally have low quality litter. This low quality litter decomposes slowly which adds more carbon to the soil [51]. Litter quality has been found to be related to precipitation, in that increased precipitation leads to lower litter quality [50,51]. Therefore, switchgrass cultivars with increased lignin content in the litter produced may lead to higher carbon additions to the soil.

5.3. *Soil erosion and SOC*

Erosion and land degradation are accentuated through losses of soil organic carbon (SOC) [52]. The loss of the SOC pool is due primarily to three factors: (1) the reduction in plant roots (2) the increase in biological activity as soil aeration is increased by cultivation and soil temperature, and (3) increase in soil erosion that removes carbon-rich materials. To minimize negative ecological impacts of switchgrass biofuel production, SOC losses must be minimized. No till farming has been shown to slow erosion and build SOC matter when residue inputs are sufficient [53]. These residue inputs reduce

SOC loss and provide for the maintenance of soil structure and resistance from soil erosion [12]. Land maintenance has important consequences because degraded soil structure and the loss of SOC increases the greenhouse gas carbon dioxide and accelerates soil erosion losses [54,55].

Rehabilitation of degraded soil can be accomplished using appropriate bioenergy crops to improve soil productivity and restore the SOC pool. Switchgrass can restore the SOC in surface soils (0–30 cm) and stabilize the soil with its deep root system (>1 m) [52]. The root system of switchgrass has the potential to lower soil erosion rates 30 times in the establishment year, and 600 times in the second and third years compared to annual crop production [12,56]. Decreases in soil erosion rates result from a well-developed litter layer and increases of other carpet grasses such as fescue or smooth brome [57]. For this reason, bioenergy crops can be grown on marginal soils with low productivity to rehabilitate this degraded land. Recent estimates suggest great potential for increasing the SOC pool using biofuels. Estimates suggest up to 3 T-ha-yr^{-1} of soil carbon can be sequestered under perennial grass biofuels like switchgrass [17,52]. There are 10.8 Mha of severely eroded soils in the United States that may benefit from growing bioenergy crops and adoption of conservation-effective practices [52].

5.4. *Carbon sequestration*

The high productivity of grassland perennials like switchgrass increases the amount of carbon sequestered in degraded soils from the extensive root systems and large amounts of leaf litter [5,58–61]. The belowground biomass of switchgrass is four to five times greater than that of corn, with the potential to input 2.2 Mg C ha^{-1} yr^{-1} into soils [52,62]. Switchgrass root systems increase the amount of SOC due to the size of the root systems, slow decomposition rates of root biomass [59,63], and root secretion of organic compounds bind soil particles and stabilize the SOC [59,64]. However, as with any productive grass population, switchgrass stands are a large carbon source due to the respiration from the extensive root systems and associated microbial communities. The microbial CO_2 emissions depend on the amount of labile carbon available in the form of leaf litter and crop residue [59,65,66]. For example, Al-Kaisi and Grote (2007) [59] reported annually harvested switchgrass crop systems exhibited higher soil CO_2 emissions than switchgrass crop systems harvested at five year intervals [59]. Al-Kaisi and Grote suggest difference in CO_2 emissions between the two harvesting techniques may be due to larger root biomass of individuals in the annually harvested treatment and higher microbial biomass carbon content [59]. Despite CO_2 emissions from grasslands and biofuel cropping systems from microbial and root respiration, these systems are generally viewed as net carbon sinks [58,67–70].

The degree to which switchgrass or any other biofuel can act as an agent for carbon sequestration depends on the soil environment. The soil environment includes soil quality, soil type, soil moisture, soil temperature, and the carbon to nitrogen ratio of the substrate (leaf litter and residue) [50]. For instances, the initial SOC and soil type determine how quickly switchgrass stands can sequester carbon [71]. In addition, management practices, climate, and cultivar selection may influence carbon sequestration [5]. The research of Lee et al. (2007) [61] showed that carbon sequestered at depths of 30 cm–90 cm increased when manure was applied as the N source for switchgrass grown on CRP land. Frank et al. (2004) [58] reported that seasonal changes in temperature and soil moisture were the primary determinants of soil CO_2 flux in switchgrass cultivation. CO_2 flux throughout the season corresponded with changes in temperature and lower CO_2 fluxes were associated with decreased soil moisture [58]. Moreover, Al-Kaisi and Grote (2007) [59] suggest switchgrass cropping systems can potentially contribute more to soil carbon sequestration than corn-soybean rotations due to the more extensive root system of switchgrass. Furthermore, a study conducted by Tilman et al. (2006) [17] argues that low-input high diversity (LIHD) biofuels have the greatest potential for carbon sequestration compared to monocultures. LIHD biofuels are carbon-negative because the net carbon sequestration is much greater than the CO_2 released during the biofuel production [17]. Biofuel crops will continue to sequester greater amounts of soil carbon until the system reaches equilibrium. At equilibrium, any biofuel cropping system (i.e., switchgrass) becomes a carbon reservoir [5]. It is estimated that switchgrass cropping systems have the potential to reach equilibrium around fifty years after establishment [52].

6. Conclusion

As consideration of switchgrass as a biofuel resource continues to develop in the future, the potential ecological implications of cultivating this crop across large sections of the central United States must be considered. These impacts can be measured by the abundance and diversity of wildlife, potential for disease and invasions, changes in soil quality, erosion, and carbon sequestration. To date, the greatest ecological consideration of the impacts of widespread switchgrass cultivation has been focused on the ability of switchgrass to sequester carbon. However, the other considerations discussed (e.g., the effects on wildlife, changing land use, disease, invasive potential, and soil quality) should also be considered when evaluating the consequences of switchgrass as a biofuels [52,72]. One of the central tenets associated with maximizing the structural and functional characteristics of grassland ecosystems following switchgrass cultivation is the maintenance of landscape heterogeneity. Landscape heterogeneity is maximized by altered harvest rotations, no till farming, and mixed species composition. Increased structural diversity facilitates greater species abundance and species diversity because more habitat is available. Additionally, landscape heterogeneity increases the quality of the soil, and provides greater genetic variation within the community. To date, most research investigating the ecological impacts of switchgrass cultivation has been short-term, emphasizing the need for long-term assessment of impacts and consequences [42,43]. Regardless of the species and technique, biofuel production in agricultural lands, marginal lands, and grasslands has ecosystem consequences that must be considered, but current research suggests that low-input switchgrass cultivation across a heterogeneous landscape can increase ecosystem services as well as provide economic value.

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REFERENCES

[1] Weaver JE, Fitzpatrick TJ. Ecology and relative importance of the dominants of tall-grass prairie. Bot Gaz 1932;93:113–50.
[2] Smith MD, Knapp AK. Dominant species maintain ecosystem function with non-random species loss. Ecol Lett 2003;6:509–17.
[3] Casler MD, Vogel KP, Taliaferro CM, Wynia RL. Latitudinal adaptation of switchgrass populations. Crop Sci 2004;44:293–303.
[4] Das MK, Fuentes RG, Taliaferro CM. Genetic variability and trait relationships in switchgrass. Crop Sci 2003;44:443–8.
[5] Parrish DJ, Fike JH. The biology and agronomy of switchgrass for biofuels. Crit Rev Plant Sci 2005;24:423–59.
[6] Porter CL. An analysis of variation between upland and lowland switchgrass *Panicum virgatum* L in central Oklahoma. Ecology 1966;47:980–92.
[7] Casler MD. Ecotypic variation among switchgrass populations from the northern USA. Crop Sci 2005;45:388–98.
[8] Qin X, Mohan T, El-Halwagi M, Cornforth G, McCarl BA. Switchgrass as an alternate feedstock for power generation: an integrated environmental, energy and economic life-cycle assessment. Clean Technol Environ Policy 2006;8:233–49.
[9] Sanderson MA, Adler PR, Boateng AA, Casler MD, Sarath G. Switchgrass as a biofuels feedstock in the USA. Can J Plant Sci 2006;86:1315–25.
[10] Brown RA, Rosenberg NJ, Hays CJ, Easterling WE, Mearns LO. Potential production and environmental effects of switchgrass and traditional crops under current and greenhouse-altered climate in the central United States: a simulation study. Agric Ecosyst Environ 2000;78:31–47.
[11] Barney JN, DiTomaso JM. Bioclimatic predictions of habitat suitability for the biofuel switchgrass in North American under current and future climate change scenarios. Biomass Bioenergy 2010;34:124–33.
[12] Williams PRD, Inman D, Aden A, Heath GA. Environmental and sustainability factors associated with next-generation biofuels in the U.S.: what do we really know? Environ Sci Technol 2009;43:4763–75.
[13] Tilman D, Socolow R, Foley JA, Hill J, Larson E, Lynd L, et al. Beneficial biofuels—The food, energy, and environment Trilemma. Science 2009;325:270–1.
[14] Bouton J. The economic benefits of forage improvement in the United States. Euphytica 2007;154:263–70.
[15] Jessup JW. Development and status of dedicated energy crops in the United States. In Vitro Cell Dev Biol-Plant 2009;45:282–90.
[16] Varvel GE, Vogel KP, Mitchell RB, Follett RF, Kimble JM. Comparison of corn and switchgrass on marginal soils for bioenergy. Biomass Bioenergy 2008;32:18–21.
[17] Tilman D, Hill J, Lehman C. Carbon-negative biofuels from low-input high-diversity grassland biomass. Science 2006;314:1598–600.
[18] USDA [Internet]. Conservation Policy: Land Retirement Programs [update 2009 Feb 6, cited 2010 Jan 28]. Available from: http://www.ers.usda.gov/Briefing/ConservationPolicy/retirement.htm.
[19] Claassen R, Hansen L, Peters M, Breneman V, Weinberg M, Cattaneo A, et al. Agri-Environmental policy at the crossroads: guideposts on a changing landscape. Agr Econ Report 2001;794:1–67.
[20] Niemuth ND, Quamen FR, Naugle DE, Reynolds RE, Estey ME, Shaffer TL. Benefits of the conservation reserve program to grassland bird populations in the prairie Pothole region of North Dakota and South Dakota. United States Department of Agriculture Farm Service Agency; 2007.
[21] Walsh ME, Ugarte DGD, Shapouri H, Slinsky SP. Bioenergy crop production in the United States - Potential quantities, land use changes, and economic impacts on the agricultural sector. Environ Res Econ 2003;24:313–33.
[22] Schmer MR, Vogel KP, Mitchell RB, Moser LE, Eskridge KM, Perrin RK. Establishment stand thresholds for switchgrass grown as a bioenergy crop. Crop Sci 2006;46:157–61.
[23] Hoffman W, Beyea J, Cook JH. Ecology of agricultural monocultures: some consequences for biodiversity in biomass energy farms. NREL/CP-200-8098. In: Proceedings of the second biomass conference of the Americas: energy, environment, agriculture, and industry. Portland, Oregon. Golden, Colorado: National Renewable Energy Laboratory; 1995. p. 1618–27.
[24] Gonzalez-Hernandez JL, Sarath G, Stein JM, Owens V, Gedye K, Boe A. A multiple species approach to biomass production from native herbaceous perennial feedstocks. In Vitro Cell Dev Biol-Plant 2009;45:267–81.
[25] Crouch JA, Beirn LA, Cortese LM, Bonos SA, Clarke BB. Anthracnose disease of switchgrass caused by the novel fungal species *Colletotrichum navitas*. Mycol Res 2009;113:1411–21.
[26] Prasifka JR, Bradshaw JD, Meagher RL, Nagoshi RN, Steffey KL, Gray ME. Development and feeding of fall armyworm on *Miscanthus* x *giganteus* and switchgrass. Field Forage Crop 2009;102:2154–9.
[27] Cornelius DR, Johnston CO. Differences in plant type and reaction to rust among several collections of *Panicum virgatum* L. Agron J 1941;33:115–24.
[28] Barnett FL, Carver RF. Meiosis and pollen stainability in switchgrass, *Panicum virgatum* L. Crop Sci 1967;7:301–4.
[29] Gustafson DM, Boe A, Jin Y. Genetic variation for *Puccinia emaculata* infection in switchgrass. Crop Sci 2003;43:755–9.
[30] Simberloff D. Invasion biologists and the biofuels boom: cassandras or colleagues? Weed Sci 2008;56:867–72.
[31] Pyke CR, Thomas R, Porter RD, Hellmann JJ, Dukes JS, Lodge DM, et al. Current practices and future opportunities for policy on climate change and invasive species. Conserv Biol 2008;22:585–92.
[32] Barney JN, DiTomaso JM. Nonnative species and bioenergy: are we cultivating the next invader? Bioscience 2008;58:64–70.
[33] Bies L. The biofuels explosion: is green energy good for wildlife? Wildl Soc Bull 2006;34:1203–5.
[34] Paine LK, Peterson TL, Undersander DJ, Rineer KC, Bartelt GA, Temple SA, et al. Some ecological and socio-economic considerations for biomass energy crop production. Biomass Bioenergy 1996;10:231–42.
[35] Milder JC, McNeely JA, Shames SA, Scherr SJ. Biofuels and ecoagriculture: can bioenergy production enhance landscape-scale ecosystem conservation and rural livelihoods? Int J Agr Sustain 2008;6:105–21.
[36] McCoy TD, Ryan MR, Burger LW, Kurzejeski EW. Grassland bird conservation: CP1 vs. CP2 plantings in conservation reserve program fields in Missouri. Am Midl Nat 2001;145:1–17.
[37] Semere T, Slater FM. Ground flora, small mammal and bird species diversity in miscanthus (*Miscanthus x giganteus*) and

reed canary-grass (*Phalaris arundinacea*) fields. Biomass Bioenergy 2007;31:20–9.

[38] Murray LD, Best LB. Short-term bird response to harvesting switchgrass for biomass in Iowa. J Wildl Manage 2003;67: 611–21.

[39] Perlut NG, Strong AM, Donovan TM, Buckley NJ. Regional population viability of grassland songbirds: effects of agricultural management. Biol Conserv 2008;141:3139–51.

[40] Roth AM, Sample DW, Ribic CA, Paine L, Undersander DJ, Bartelt GA. Grassland bird response to harvesting switchgrass as a biomass energy crop. Biomass Bioenergy 2005;28:490–8.

[41] Murray LD, Best LB, Jacobsen TJ, Braster ML. Potential effects on grassland birds of converting marginal cropland to switchgrass biomass production. Biomass Bioenergy 2003;25: 167–75.

[42] Keshwani DR, Cheng JJ. Switchgrass for bioethanol and other value-added applications: a review. Bioresour Technol 2009; 100:1515–23.

[43] Bellamy PE, Croxton PJ, Heard MS, Hinsley SA, Hulmes L, Hulmes S, et al. The impact of growing miscanthus for biomass on farmland bird populations. Biomass Bioenergy 2009;33:191–9.

[44] Nixon ES, McMillan C. The role of soil in the distribution of four grass species in Texas. Am Midl Nat 1964;71:114–40.

[45] Evers EW, Parsons MJ. Soil type and moisture level influence on Alamo switchgrass emergence and seedling growth. Crop Sci 2003;43:288–94.

[46] Barney JN, Mann JJ, Kyser GB, Blumwald E, Van Deynze A, DiTomaso JM. Tolerance of switchgrass to extreme soil moisture stress: ecological implications. Plant Sci 2009;177: 724–32.

[47] Johnson JMF, Barbour NW, Weyers SL. Chemical composition of crop biomass impacts its decomposition. Soil Sci Soc Am J 2007;71:155–62.

[48] Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I, et al. Regional climate projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL, editors. Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge, United Kingdom and New York, USA: Cambridge University Press; 2007.

[49] Knapp AK, Smith MD. Variation among biomes in temporal dynamics of aboveground primary production. Science 2001; 291:481–4.

[50] Bontti EE, Decant JP, Munson SM, Gathany MA, Przeszlowska A, Haddix ML, et al. Litter decomposition in grasslands of central North America (US great plains). Global Change Biol 2009;15:1356–63.

[51] Murphy KL, Burke IC, Vinton MA, Lauenroth WK, Aguiar MR, Wedin DA, et al. Regional analysis of litter quality in the central grassland region of North America. J Veg Sci 2002;13: 395–402.

[52] Lemus R, Lal R. Bioenergy crops and carbon sequestration. Crit Rev Plant Sci 2005;24:1–21.

[53] Sampson RN. Carbon sequestration: what's the best approach? presented at: CARBON: exploring the benefits to farmers and society. Des Moines: Iowa; 2000 Aug 30.

[54] Blanco-Canqui H, Lal R. Soil and crop response to harvesting corn residue for biofuel production. Geoderma 2007;141: 355–62.

[55] Fargione J, Hill J, Tilman D, Polasky S, Hawthorne P. Land clearing and the biofuel carbon debt. Science 2008;319: 1235–8.

[56] McLaughlin SB, Ugarte DGDL, Garten CT, Lynd LR, Sanderson MA, Tolbert VR, et al. High-value renewable energy from prairie grasses. Environ Sci Technol 2002;36: 2122–9.

[57] Mann L, Tolbert V. Soil sustainability in renewable biomass plantings. Ambio 2000;29:492–8.

[58] Frank AB, Berdahl JD, Hanson JD, Liebig MA, Johnson HA. Biomass and carbon partitioning in switchgrass. Crop Sci 2004;44:1391–6.

[59] Al-Kaisi MM, Grote JB. Cropping systems effects on improving soil carbon stocks of exposed subsoil. Soil Sci Soc Am J 2007;71:1381–8.

[60] Lee DK, Doolittle JJ, Owens VN. Soil carbon dioxide fluxes in established switchgrass land managed for biomass production. Soil Biol Biochem 2007;39:178–86.

[61] Lee DK, Owens VN, Doolittle JJ. Switchgrass and soil carbon sequestration response to ammonium nitrate, manure, and harvest frequency on conservation reserve program land. Agron J 2007;99:462–8.

[62] Zan C, Fyles JM, Girourard P, Samson R, Doan M. Carbon storage in switchgrass and short-rotation willow plantations. In: Overend RP, Chornet E, editors. Making a business from biomass in energy, environment, chemicals, fibers, and materials. Proceedings of the third biomass conference of the Americas: energy, environment, agriculture, and industry. August 24–29, Montŕeal, Qúebec, Canada. New York: Pergamon; 1997. p. 355–61.

[63] Puget P, Drinkwater LE. Short-term dynamics of root- and Shoot-derived carbon from a leguminous green manure. Soil Sci Soc Am J 2001;65:771–9.

[64] Bronick CJ, Lal R. Soil structure and management: a review. Geoderma 2005;124:3–22.

[65] Franzluebbers AJ, Haney RL, Hons FM, Zuberer DA. Determination of microbial biomass and nitrogen mineralization following rewetting of dried soil. Soil Sci Soc Am J 1996;60:1133–9.

[66] Wang WJ, Dalal RC, Moody PW, Smith CJ. Relationships of soil respiration to microbial biomass, substrate availability and clay content. Soil Biol Biochem 2003;35: 273–84.

[67] Frank AB, Sims PL, Bradford JA, Mielnick PC, Dugas WA, Mayeux HS. Carbon dioxide fluxes over three great plains grasslands. In: Follett RF, et al., editors. The potential of U.S. grazing lands to sequester carbon and mitigate the greenhouse effect. Baco Raton, FL: CRC Press; 2001. p. 167–87.

[68] Frank AB, Dugas WA. Carbon dioxide fluxes over a northern semiarid, mixed-grass prairie. Agri Forest Meterol 2001;108: 317–26.

[69] Sims PL, Bradford JA. Carbon dioxide fluxes in a southern plains prairie. Agr Forest Meterol 2001;109:117–34.

[70] Suyker AE, Verma SB. Year-round observations of the net ecosystem exchange of carbon dioxide in a native tallgrass prairie. Global Change Biol 2001;7:279–89.

[71] Garten CT, Wullschleger SD. Soil carbon dynamics beneath switchgrass as indicated by stable isotope analysis. J Environ Qual 2000;29:645–53.

[72] Raghu S, Anderson RC, Daehler CC, Davis AS, Wiedenmann RN, Simberloff D, et al. Adding biofuels to the invasive species fire? Science 2006;313:1742.