Biomass and Bioenergy 92 (2016) 98–105

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: http://www.elsevier.com/locate/biombioe

Research paper

Balancing biofuel production and biodiversity: Harvesting frequency effects on production and community composition in planted tallgrass prairie

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ARTICLE INFO

Article history:
Received 16 February 2016
Received in revised form
8 June 2016
Accepted 16 June 2016

Keywords:
Agroecology
Biodiversity
Biomass production
Ecosystem functioning
Grassland
C_4 versus C_3 grasses

ABSTRACT

Native perennial grasslands have been proposed as a source of feedstocks for the production of second-generation lignocellulosic biofuels in the Midwestern USA. Although the consequences of some management decisions for biomass production and plant community composition are well understood (e.g. fertilization), less is known about the effects of harvesting frequency. We compared a once- and twice-annual harvesting regime at two restored prairies in southwestern Michigan established with identical seed mixtures as part of a large-scale bioenergy experiment. We determined biomass production and species composition in experimental plots and also measured the availability of light, inorganic nitrogen and soil moisture. The plant communities that established at the two sites differed markedly in composition and there was little evidence of convergence after five years. At the site dominated by warm-season C_4 grasses, single harvests generally produced more biomass than double harvests. By contrast, biomass production was unaffected by harvesting at the more diverse site. Contrary to our prediction that a summer harvest would increase diversity, we found small and subtle effects on plant community composition. This may be due in part to the timing of our harvest treatment. Our results suggest that a single, end-of-season harvest is the best practice for maximizing biomass production in prairies, especially at sites where warm-season grasses dominate. However, at more diverse sites, two harvests can produce the same total biomass and may support other beneficial ecosystem services. This study indicates that in the short term, double harvests are unlikely to affect plant species diversity or community composition in prairie plantings.

1. Introduction

A number of recent papers have suggested that native perennial grasslands can be used as lignocellulosic feedstocks for the production of biofuel, especially on marginal lands [1–3]. Second-generation lignocellulosic biofuels are made by breaking down plant fibrous biomass (i.e. leaves, stems, wood) into their component sugars, which are then turned into ethanol, typically by fermentation [4]. Unlike current generations of ethanol derived from corn grain, lignocellulosic biofuels rely on dedicated energy crops, such as native perennial grasses [4,5]. A number of experimental studies have shown that aboveground biomass production in grasslands is related to the relative abundance of highly productive species as well as species richness or diversity [6]. Although productivity of mixed-species perennial grasslands may not outperform the production of managed monocultures of traditional energy crops, they can provide important ecological services such as maintaining pollinator populations or reducing greenhouse gas

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http://dx.doi.org/10.1016/j.biombioe.2016.06.012
0961-9534/

emissions from soils [5,7,8]. Management practices such as fertilization and the frequency or timing of harvesting can affect productivity and community composition of grasslands, and so are likely to affect ecological services dependent on plant biodiversity or composition [9,10]. While the impact of fertilization on biomass production and composition/diversity has been well documented [11–13], relatively few studies have focused on how harvest frequency in grasslands will affect productivity and plant biodiversity in the context of bioenergy production.

Developing management for bioenergy grasslands to assure both consistent high biomass yield and maintenance of the plant community composition necessary for other ecosystem services will be challenging. Fertilization increases productivity, but typically results in declines in species diversity [11,13,14]. The negative effects of fertilization on diversity, however, might be offset by management that increases light availability [9,15,16]. In grasslands, grazing, fire and/or frequent harvests have been shown to prevent the accumulation of plant litter and/or reduce aboveground biomass, which increases light availability and allows certain functional groups (e.g. small-statured forbs) to persist where they might otherwise be excluded [17–19]. Thus, harvesting done early in the growing season could have a positive effect on the abundance of low-statured species, particularly forbs, by reducing the biomass of tall, warm-season, perennial grasses that often dominate grasslands planted for biofuel feedstock [20,21]. However, warm-season grasses may overcompensate for early removal of biomass with increased late-season production [[22, 23], but see [24]]. If so, then multiple harvests might result in higher total aboveground biomass and dominance by these species rather than an increase in plant diversity or forb abundance. Alternatively, multiple harvests could result in both outcomes: an increase in light allowing the persistence of short-statured species and enhanced regrowth in C_4 grasses due to the reduction of competition with cool-season C_3 grasses.

In Midwestern grasslands grown for lignocellulosic biofuels, the abundance of warm-season C_4 grasses will be a primary determinant of aboveground productivity and the magnitude of the response of productivity to fertilization [25–27]. Understanding the response of C_4 grasses to different harvesting regimes is therefore particularly important for revealing potential tradeoffs between managing for both productivity and species diversity in these systems. Most studies to date have found a single harvest in late fall maximizes the productivity of C_4 grasses relative to harvests at different times of year or higher frequencies [28–31]. The addition of a summer harvest, however, could be attractive to farmers for reasons unrelated to maximizing productivity. For example, in spring and early summer prior to anthesis of the C_4 grasses, prairie biomass is nutritious animal forage [32–34]. Increases in the abundance of subdominant forbs or legumes following summer harvests may also increase the suitability of plant communities for wildlife [35] or enhance pollinators and predatory insects [7].

In this paper we take advantage of a unique experiment begun by the Great Lakes Bioenergy Research Center (GLBRC) to compare performance of alternative bioenergy crops in large field trials. We used fields planted with a native prairie seed mixture at two sites in southwest Michigan using methods and agronomic practices likely to be implemented by commercial growers of biofuel feedstocks. The two sites had different land-use history and soil fertility, allowing us to test if these attributes affect responses to harvest. In this study, we address the following questions: (1) How does the frequency of harvesting affect total productivity and community composition at these sites? And (2) What is the relationship between species composition and response to harvesting? The answer to the latter question can only be inferred as we have not manipulated species composition within the context of our experimental treatments, and with only two sites we have no replication of the site differences. Insights from this comparison, however, will be of use to guide prediction and modeling efforts if restored prairie communities are to be considered as a source for lignocellulosic biofuel production.

2. Materials and methods

2.1. Study sites

We conducted our study at two sites in southwestern Michigan – Lux Arbor (42°28′23″ N, 85°26′50″ W) and Marshall Farm (42°26′37″ N, 85°18′34″ W) – that were used in the establishment of biofuel cropping systems by GLBRC. Though managed in the same way for this experiment, the two sites differed in soil type, total soil resource pools and prior agricultural management (Table 1). In 2009, both sites were prepared for conversion to prairie with the application of a non-selective foliar herbicide and one year of no-till soybean cultivation (see online supplementary material for detailed agronomic information). The same mix of prairie species (Table 2) was sown into both sites in June 2010 using a no-till seed drill. The seed mix was selected to provide a balance between biomass production of high-yielding grass species, diversity of important tallgrass prairie functional groups and affordability for seeding large sites. Neither site was fertilized after planting. Annual mechanical harvest for biomass began in the fall of 2011, after the plants had time to establish.

Our study was conducted from 2012 to 2014. Growing season precipitation differed among the three years; in 2012 it was well below average, particularly from May–July, whereas 2013 and 2014 had more typical rainfall (Fig. S1). Drought conditions in 2012 ranged from abnormally dry to severe drought according to the National Drought Mitigation Center (http://droughtmonitor.unl.edu/). In the following years, by contrast, no drought conditions occurred during the growing season. We consider in our interpretation of the harvesting effects on production the influence of large inter-annual differences in precipitation.

2.2. Multiple harvest experimental design

To determine the effects of multiple harvests on biomass production and species composition, in 2012 we established a harvest frequency experiment at both sites. Six replicate blocks were placed at least 25 m apart in each site. Each block had two 5 × 5 m treatment plots, one of which was harvested twice each growing season (July & late September – double harvest treatment) and the other was harvested once (late September – single harvest treatment). These harvesting times were chosen to coincide with when farmers and ranchers in the North Central US might cut warm-season grasses for forage (summer, when grasses are in the early boot stage) and when harvests for biofuel feedstocks occur (fall) [29,32,34,36]. Our summer harvest falls within the range of times typical for haying pastures containing mixed warm-season grasses [37–40]. The fall experimental harvests took place one to two weeks before the mechanical harvest of the entire field. In each plot, a 0.5 × 2 m area in the plot center was harvested by hand, leaving stubble approximately 10 cm tall to mimic the biomass removal of mechanical harvests. The harvested biomass was sorted to species in the field, oven-dried and weighed. The remaining area of the treatment plot was cut to 10 cm height with a weed-whacker and raked to remove the biomass, also mimicking the effects of mechanical harvest.

The experimental harvests were done annually from 2012 to 2014; however, the location of the treatment blocks within the field