European Journal of Agronomy 101 (2018) 121–128

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Perennial biomass crop establishment, community characteristics, and productivity in the upper US Midwest: Effects of cropping systems seed mixtures and biochar applications

Catherine L. Bonin[a], Rivka B. Fidel[a], Chumki Banik[a], David A. Laird[a], Robert Mitchell[b], Emily A. Heaton[a,*]

[a] Department of Agronomy, Iowa State University, Ames, IA, USA
[b] United States Department of Agriculture Agricultural Research Service and the University of Nebraska-Lincoln, Lincoln, NE, 68583, USA

A R T I C L E I N F O

Keywords:
Switchgrass
Diversity
Establishment
Yields
Warm season grass
Biochar

A B S T R A C T

Native perennial plants have potential as bioenergy feedstocks, but their use is currently limited by relatively long establishment times and low biomass yields. Some research suggests that incorporating plant species diversity and applying biochar as a soil amendment might alleviate these limitations by creating a more resilient crop and soil system. The objective of this research was to investigate how 1) seeded plant diversity and 2) biochar soil amendments interact to affect the establishment, yield, and plant species composition of biomass cropping systems during the first four years of growth on productive soils. We measured species emergence, cover, peak and post-frost biomass, and biomass composition for three biomass cropping systems seed mixtures – a switchgrass monoculture, a three-species grass mixture, and a highly diverse mixture of grasses and forbs – either with or without application of a mixed wood gasification biochar (9.3 Mg ha^{-1}). We found that seed mixture had significant effects on nearly every variable measured, with switchgrass monocultures outperforming the two more diverse mixtures by the third year of the experiment (12.0 Mg ha^{-1} in switchgrass, 8.7 Mg ha^{-1} in low diversity plots, and 3.9 Mg ha^{-1} in high diversity plots), despite an initial switchgrass establishment failure. The high diversity plots exhibited poor sown species establishment in the first year due to high weed pressure in a drought year, but continued to improve over time. Biochar application had no consistent effect on plant biomass or community traits, and significantly affected only two community traits, light transmittance and leaf area index. Our results suggest that on productive soils perennial bioenergy productivity may be achieved through selection of one or a few high-yielding grass species, with little or no effect of biochar applications on perennial biomass crop establishment, diversity, or productivity.

1. Introduction

As atmospheric carbon dioxide concentrations increase, there is a growing interest for agricultural practices that mitigate and adapt to global climate change. One such option is to reduce fossil fuel usage through the development of renewable bioenergy from native perennial biomass crops that can be grown over a broad range of conditions. This bioenergy option has several agricultural benefits, including reduced competition with food production and reduced agricultural inputs compared to non-cellulosic crops, as well as improved energy balance and provision of ecosystem services (Lewandowski et al., 2003; Valentine et al., 2012; Werling et al., 2014). Such benefits are particularly important in the Corn Belt of the upper Midwestern US, where conventional agricultural practices in maize (*Zea mays* L.) and soy (*Glycine max* Merr.) cropping systems contribute to widespread soil and water quality degradation (US Environmental Protection Agency, 2015).

Among US native perennials, the C_4 grass switchgrass (*Panicum virgatum* L.) was one of the first species identified by the US Department of Energy as a promising biomass crop, largely due to its broad ecological adaptation and high yield potentials (Parrish and Fike, 2005).While switchgrass and other bioenergy grass monocultures can provide large quantities of biomass and a variety of ecosystem services, incorporating plant diversity into perennial biomass cropping systems

* Corresponding author at: 1403 Agronomy Hall, 716 Farm House Lane, Iowa State University, Ames, IA, 50010, USA.
E-mail addresses: cathib23@gmail.com (C.L. Bonin), rfidel@iastate.edu (R.B. Fidel), cbanik@iastate.edu (C. Banik), dalaird@iastate.edu (D.A. Laird), rob.mitchell@ars.usda.gov (R. Mitchell), heaton@iastate.edu (E.A. Heaton).

https://doi.org/10.1016/j.eja.2018.08.009
Received 1 May 2017; Received in revised form 31 July 2018; Accepted 29 August 2018
1161-0301/

can further improve ecosystem services such as the provisioning of forage and fuel, wildlife habitat, and ecosystem stability (Tilman et al., 2006; Isbell et al., 2015; Zilverberg et al., 2016). One major challenge to using native perennials is their slow establishment, as it may take up to three years for a stand to fully mature (McLaughlin and Kszos, 2005). During this time, perennial fields may be at increased risk for soil erosion and invasion by undesirable weedy species, both of which can deleteriously affect biomass productivity and other ecosystem services. Increasing seeded plant diversity may help alleviate weed pressure and reduce erosion during the establishment period through rapid ground cover by desirable species (Tilman, 1997; Fargione and Tilman, 2005; Bonin et al., 2014). Others point out that higher plant diversity may reduce ethanol yields (Adler et al., 2009), that plant diversity may decline over time and yields remain unstable (Von Cossel and Lewandowski, 2016), and that ecosystem benefits observed in small-plot diversity experiments may not hold true in large-scale biomass crop plantations (Dickson and Gross, 2015). One potential solution to address these concerns is establishment of a moderately diverse mixture of high-yielding plant species that balances the benefits and challenges of both monocultures and highly diverse plant mixtures (DeHaan et al., 2010; Bonin and Tracy, 2012).

A second option for mitigating greenhouse gases may be biochar production and application to soil (Lehmann, 2007; Laird, 2008). Biochar, a carbon-rich product of biomass pyrolysis, can be used as a soil amendment for multiple purposes such as long-term carbon storage, to improve soil quality, and to increase crop productivity (Ippolito et al., 2012; Laird, 2008). Plant productivity responses to biochar may be affected by a variety of factors, including biochar characteristics, biochar feedstocks, application rate, crop type, and soil properties (Jeffery et al., 2011; Biederman and Harpole, 2013). Much biochar research has focused on traditional annual crops such as maize and wheat (*Triticum aestivum*), and less is known about how biochar amendments may affect perennial biomass cropping systems. Research on the effects of biochar on perennials has often generated equivocal and/or inconsistent results. For example, some experiments report that biochar has positive effects on switchgrass yield (Edmunds, 2012), and that it may improve the height and biomass of big bluestem (*Andropogon gerardii* Vitman), but not the legume sericea lespedeza [*Lespedeza cuneata* (Dum. Cours.) G. Don] (Adams et al., 2013). In contrast, another experiment demonstrated that legume biomass, but not overall community productivity, increased following biochar application in a restored grassland (van de Voorde et al., 2014). Another study suggests that biochar application could increase plant species richness, but in order to observe increases in biomass, the application rate had to be relatively high (56.8 Mg ha^{-1}, Biederman et al., 2017). Meta-analyses suggest that biochar has, on average, a positive effect on cropping system productivity; however, when separated out, studies investigating perennial crops have shown no increase or even a decrease in yield with biochar application (Jeffery et al., 2011; Biederman and Harpole, 2013).

No prior publications have investigated interactions between biochar amendments and perennial biomass cropping systems seeded diversity, presenting a gap in knowledge on how these two management choices may impact the viability of bioenergy cropping systems. Here we ask whether 1) biochar soil amendments will influence native perennial crop establishment and plant growth, 2) if planting more diverse perennial cropping systems (switchgrass monoculture vs. low-diversity mixture vs. high-diversity mixture) will result in greater aboveground productivity, and finally, 3) if biochar applications will act synergistically with seeded species diversity to further boost productivity.

2. Materials and methods

2.1. Study site and experimental design

The experiment was established at Armstrong Memorial Research and Demonstration Farm, located near Lewis, IA (41.311250, −95.179493) on land that had previously been planted in a maize-soy rotation. Experimental plots ranged from flat to slightly sloping, and were comprised primarily of loess-derived silt loams and silty clay loams. The soil types within the experiment included Marshall (Fine-silty, mixed, superactive, mesic Typic Hapludolls), Exira (Fine-silty, mixed, superactive, mesic Typic Hapludolls), Clarinda (Fine, smectitic, mesic Vertic Argiaquolls), and Ackmore-Colo-Judson complex (complex of Fine-silty, mixed, superactive, mesic Cumulic Endoaquolls, Cumulic Hapludolls, and Mollic Fluvaquents) (Soil Survey Staff, 2014). These soils contained predominantly silt, as well as 4–160 g kg^{-1} clay and 40–390 g kg^{-1} sand; other soil properties are described in Table 1.

Table 1
Average physical and chemical properties of the soils prior to biochar application at Armstrong Farm in IA, USA.

Properties	0–15 cm	15–30 cm	0–30 cm
Bulk density (g cm^{-3})	1.22	1.21	1.21
pH	6.43	6.05	6.24
Electrical conductivity(μS cm^{-1})	128.45	85.07	106.76
N (%)	0.20	0.12	0.16
C (%)	1.95	1.32	1.63
C:N	9.88	11.11	10.50

A split-plot design was used with the whole plots (0.330 ha in size) receiving seed mixture treatments and the subplots (0.165 ha) receiving biochar treatments. The whole-plot cropping system treatments were: (1) a switchgrass monoculture (SG) established under a maize companion crop (following Hintz et al., 1998), (2) a low-diversity (LD) polyculture of high-yielding native grass species, and (3) a high-diversity (HD) polyculture of prairie grasses and forbs. These three cropping systems were designed to be managed differently based on sown species diversity, similar to Tilman et al. (2006); in this case, the two lower diversity treatments received higher fertilizer inputs than the high diversity treatment. There were four replications of each cropping system. The split-plot treatment, biochar, was randomly applied to one half of each whole plot in late October of 2011 at a rate of 9.3 Mg ha^{-1} (dry weight equivalent) and immediately incorporated to a depth of 15 cm by chisel plow tillage followed by disking. The biochar was generated from the gasification of mixed wood (primarily *Quercus, Ulmus* and *Carya* spp. woodchips with particle sizes 0.1–2000 mm) at ∼600 °C (ICM, Inc., Colwich, KS, USA). Detailed information concerning this biochar, including chemical properties, can be found in Fidel et al., 2017a; and Fidel et al., 2017b. Previous chemical and thermogravimetric analyses showed that the biochar was alkaline (pH 8.8), and contained 29% ash, 16% volatile matter, and 55% fixed carbon, 63% total C, 2.7% total H, 0.6% total N, 0.06% total P and 0.86% total K on a dry weight basis (Fidel et al., 2017b).

The switchgrass cultivar used for the monoculture was 'Liberty,' a recently released biomass-type cultivar adapted to the US Midwest and Great Plains that was developed at the USDA-ARS in Lincoln, Nebraska (Vogel et al., 2014). The LD mixture was a 45:45:10 mixture of big bluestem ('Bonanza' and 'Goldmine'), indiangrass (*Sorghastrum nutans* L., 'Scout' and 'Warrior'), and sideoats grama (*Bouteloua curtipendula* (Michx.) Torr. 'Butte'), respectively. The HD mixture was comprised of 44 species of native perennial grasses, sedges, forbs, and legumes that would be typically seeded in a prairie restoration (See SI Table). Seeds for the LD and HD mixtures were obtained from Diversity Farms (Dedham, IA, USA).

Switchgrass seeds were no-till drilled into cultivated soil in May 2012 using a Great Plains Drill 1006 N T drill (Great Plains Manufacturing, Salina, KS, USA) in 19-cm width rows at a rate of ∼323 pure live seed (PLS) m^{-2}, which equated to 6.7 kg ha^{-1}, between rows of a maize companion crop. The same seeding rate was used for the LD and HD cropping systems and equated to 15.1 kg ha^{-1}. These mixes were broadcast and then cultipacked using a Vicon seeder (Kverneland Group, Klepp Stasjon, Norway) and a Brillion cultipacker (Landoll