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Yield of perennial herbaceous and woody biomass crops over time across three locations

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ABSTRACT

The use of perennial biomass crops is expected to increase and will likely be part of a diversified approach to cropping system design that focuses on multiple economic, ecological, and environmental benefits. Field experiments were conducted from 2006 to 2011 at three locations in Minnesota to quantify biomass production across a diverse set of perennial herbaceous and woody crops. Herbaceous crops were harvested annually in the fall while the woody crops were harvested once following five years of growth. Willow produced more total biomass than all other woody and herbaceous biomass crops across all locations. However, miscanthus biomass yield was similar to 'SX67' willow at St. Paul and Waseca, but was dependent on the cultivar of miscanthus. Prairie cordgrass cultivars were among the highest and most consistent yielding herbaceous biomass crops across locations. Miscanthus cultivars produced the highest annual dry matter yield of 35 Mg ha^{-1} yr^{-1} biomass, but only during the final year of the study. Other herbaceous crops such as switchgrass performed well in certain locations and may offer flexibility in cropping choice. This unique information on comparative biomass yield across a diversity of perennial crops will inform the overall decision-making process in a way that reduces risk and optimizes productivity in specific environments. This study shows that several biomass crop species can be successfully grown as part of a diversified biomass cropping enterprise.

1. Introduction

Cellulosic biomass is being considered as a feedstock for numerous bioindustrial applications [1]. Ethanol, heat, and electrical power generation are the most common platforms that use cellulosic biomass as a feedstock. Cellulosic crops have been proposed as major feedstock to achieve the 79.5 hm^3 of advanced biofuels goals by 2022 as designated by the Renewable Fuels Standards. New techniques and processes are being developed that expand the range of products being produced from biomass feedstock. For example, there is great interest in using plant biomass for the industrial production of organic compounds as well as the synthesis of new products that do not have a synthetic counterpart [1–3]. The bio-refinery concept is proposed as a method of generating even greater value by integrating the production of first and second generation transportations fuels, power, and an array of chemicals at one facility [4,5]. In this model, renewable feedstock enters the biorefinery and is converted through an array of processes into a mixture of products [6]. However,

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feedstock type and quantity are key drivers in the success of these concepts.

Most of the cellulosic feedstock for current bioindustrial applications is derived from annual crops (e.g. corn (*Zea mays* L.) stover) or perennial grasses (e.g. switchgrass (*Panicum virgatum* L.)). It has been argued that the use of perennial feedstock is the preferred choice for bioindustrial feedstock because of its economic, environmental and ecological benefits [7,8]. Boehmel [9] evaluated the performance of six cropping systems and found that the perennial cellulosic crops, willow and miscanthus, had the best combined high biomass and energy yields with high land and energy use efficiency, nitrogen fertilizer use and environmentally benign production methods compared to other annual crops. The benefits of perennial biomass crops provided by increased ecosystem services, such as enhanced wildlife habitat, nutrient sequestration, improved water quality and retention, and reduced soil erosion, are well-documented [7,10–12].

The development of a robust bioproducts industry is a recognized way to increase farmer profitability while addressing environmental, ecological, and social issues. As such, the use of perennial biomass crops is expected to increase. However, there is a great need to understand how biomass crops can be effectively managed in a sustained long-term approach [8]. Gonzalez-Hernandez et al. [13] suggest the need to evaluate multiple species with adaption to specific climate and edaphic zones because there is no one crop that will provide all the necessary attributes necessary to meet the demands of industry. Our objective was to quantify biomass yield of perennial herbaceous and woody crops over time and environment in Minnesota.

2. Materials and methods

Field studies were conducted at three University of Minnesota Research and Outreach Centers from 2006 to 2011. The locations represent a range of soils and climates typical of southern Minnesota. The three locations included St. Paul (44°59′ N, 93°1′ W), Waseca (44°43′ N, 93°06′ W), and Lamberton (44°15′ N, 95°19′ W). Locations follow a moisture gradient from western to eastern Minnesota with the eastern location (St. Paul) having the greatest amount of precipitation and the western location (Lamberton) with the least amount of precipitation during the growing season. There is also a soil texture and soil drainage pattern across Minnesota whereby the southern location (Waseca) is characterized by finer textured, poorly drained soils compared to courser textured, well drained soils of eastern and western Minnesota. Soil and environmental information for each location is presented in (Table 1). All field locations tested high for soil P and K. Nitrogen was broadcast applied as urea in each plot, except for the polyculture treatment, at a rate of 112 kg ha^{-1} N in April of each year and location. The previous crop was soybean across all locations.

The experimental design was a randomized complete block with three replications at each location. Block was restricted whereby tall woody plants were grouped so as not to alter growth of shorter herbaceous species in nearby plots. Plot size was 4.25 m × 6.25 m for the herbaceous crops and 5.00 m × 9.25 m for the woody plants. Treatments consisted of perennial woody and herbaceous plants that are being considered for biomass production. Plant material used in this study was purchased from commercial nurseries with the exception of false indigo, sunflower, Jerusalem artichoke, stiff goldenrod, and late goldenrod which were obtained locally from University of Minnesota collections in St. Paul, MN. All herbaceous crops were established from transplants with the exception of the polyculture treatment in May 2006. Woody crops were established from rooted or un-rooted cuttings. Details regarding cultivars, sources, plant spacing, and plant density are provided in Table 2.

Weed control consisted of a preemergence application of mesatrione ([2-[4-(methylsulfonyl)-2-nitrobenzoyl]-1,3-cyclohexanedione]) at 20.6 g ha^{-1} active ingredient in spring 2007 and 2008 and acetochlor (2-chloro-N-(ethoxymethyl)-N-(2-ethyl-6-methylphenyl) acetamide) at 2.2 kg ha^{-1} active ingredient in spring 2009–2011. Selective weed control consisted of a postemergence application of quizalofop ((±)-2-[4-[(6-chloro-2-quinoxalinyl)oxy]phenoxy]propanoic acid) at

Table 1 – Soil, precipitation, and temperature characteristics during the growing season (May–September) at Lamberton, Waseca, and St. Paul locations.

	St. Paul	Waseca	Lamberton
Normal precipitation (cm)[a]	52.6	51.9	42.3
Precipitation (cm)			
2007	47.8	64.2	36.4
2008	30.1	43.2	32.7
2009	28.7	27.9	32.4
2010	66.3	87.9	47.5
2011	64.4	46.8	44.8
Mean annual temp (°C)	7.8	6.6	6.8
Soil classification	Waukegan silt loam (fine-silty, mixed mesic typic hapludoll)	Nicollet clay loam (fine-loamy, mixed, superactive, mesic aquic hapludolls)	Coland clay loam (fine-loamy, mixed, superactive, mesic cumulic endoaquolls)
Soil organic matter (%[b])	4.5	5.1	4.5
Soil pH	6.3	5.8	6.5

[a] 30-year normal from 1971 to 2000.
[b] Mass fraction.