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Biomass and Energy Crops IV

Energy and conservation benefits from managed prairie biomass

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Summary

Marginally productive land, such as that enrolled in the Conservation Reserve Program (CRP), may provide acreage and economic incentives for cellulosic energy production. Improving the yields from these lands will help establish a biomass producer's position in the marketplace. The effects of water and nitrogen on biomass yields were investigated in both a plot-scale experiment and a broad-scale survey of CRP lands. The plot-scale experiment demonstrated that irrigation improved mixed-species prairie biomass yields more than nitrogen (N) fertilizer on highly degraded soils. Experimental plots amended with both irrigation and moderate (but not high) N produced more biomass than other treatment combinations, but this trend was not statistically significant. The survey of biomass yields on CRP lands across four Midwestern states suggests that yields are better correlated with June rainfall than any other individual month. Applying nutrient-enriched water such as agricultural runoff could benefit prairie yields if applied at appropriate times.

Key words: Tall-grass prairie, biomass yields, bioenergy

Introduction

The United States' Energy Independence and Security Act of 2007 (EISA, 2007) carries a mandate to produce 35 billion gallons of transportation biofuel by 2025. This is driven by the desire to reduce dependence on fossil fuels as well as to mitigate green house gases. Implementation of this mandate using traditional agricultural practices and crops will require vast land resources, potentially contribute to natural resource issues, and may lead to indirect land-use problems (Searchinger *et al*., 2008; Fargione *et al*., 2008). Producing more corn-based ethanol may increase food prices due to changing market dynamics. Alternative bioenergy options include non-food biomass feedstock from perennial crops and more sustainable land-management practices.

Prairies managed for biomass may be one alternative to conventional biofuels that can contribute to national energy goals while avoiding some of the aforementioned issues. Restoring native perennial grasslands could also provide various ecosystem services, including carbon sequestration (Conant *et al*., 2001), water quality and quantity control (Love & Nejadhashemi, 2011), habitat for wildlife (Fargione *et al*., 2009; Meehan *et al*., 2010) and resources for beneficial insects, including pollinators and natural enemies (Gardiner *et al*., 2010). Perennial grasslands, including those enrolled in the Conservation Reserve Program, can also supply a consistent biomass feedstock with minimal inputs (Tilman *et al*., 2006), but some emerging challenges have limited the viability of grassland bioenergy and more generally, the efforts to conserve the endangered tall grass prairie ecosystem.

Currently, financial advantages from corn markets and a well established corn ethanol infrastructure have tended to avert attention and investments from grassland bioenergy. One means of initiating more research and stakeholder participation in grassland bioenergy would be to improve biomass yields. This project measured prairie biomass yields in experimental field plots amended with various levels of N fertilizer and irrigation. Results from this experiment can be used in economic analyses to determine if inputs such as N and water improve yields enough to justify investments. The utility of grassland biomass as an energy source may supply the economic incentives to expand perennial grasslands and integrate them within agricultural landscapes to meet renewable energy goals, provide ecosystem services, and contribute to the conservation of native landscapes.

Materials & Methods

This experiment was conducted at Cedar Creek Ecosystem Science Reserve in Minnesota, USA. A completely randomized fully factorial design was used to measure the effects of three levels of N fertilizer and two levels of irrigation on the biomass production of diverse prairie grown on sandy, marginal soil. Six replicates of each treatment amounted to a total of 36 plots. Each plot was 9 m by 9 m and planted with 32 randomly assigned species of prairie plants in 1994. Plots treated with N were fertilized in early summer with 0, 7, or 14 g m^{-2} as ammonium nitrate. Irrigated plots were watered throughout the growing season at a rate of about 2.5 cm $week^{-1}$. Treatments were initiated in 2007 and data was collected in 2008, 2009 and 2010.

Each plot was completely harvested after each growing season (approximately late October) using a walk-behind sickle bar mower, leaving a stubble height of approximately 10 cm. Biomass was hand-racked, collected, and weighed wet. A sub-sample of biomass from each plot was weighed, dried and re-weighed to determine water content. This value was extrapolated to the total biomass weight from each plot to report dry matter yield.

A 5 m strip 10 cm wide was cut to ground level through the remaining stubble to determine harvest efficiency. The biomass from the stubble was weighed, dried and re-weighed to determine dry matter yield. The clipped biomass yield was used to determine the biomass lost from harvest inefficiency.

The stubble was burned in all plots in early spring to accelerate productivity and manage annual weeds. Three separate hand weeding events occurred each year at approximately equal intervals throughout the growing season to maintain species diversity. This was done to maintain conformity with other experiments at Cedar Creek.

Plant community data were collected from 54 restored grassland sites in 2006 in four states of the Upper Midwest, USA. Biomass yields were calculated from three points in each field with similar methods to the experimental plots. Weather data from the nearest weather station was used to identify correlations in biomass yields and total monthly precipitation.

Significant differences in mean biomass values across irrigation and fertilizer treatments were determined using analysis of variance with the computer program package R. Regression analysis correlating yields and monthly rainfall was conducted using R. Yield values from large-scale field samples were transformed using natural log to improve normality.

Results

Analysis of variance indicated that the irrigation treatment was a significant source of variation among biomass yields (Table 1). Plots amended with 2.5 cm water $week^{-1}$ produced more harvestable above ground biomass than those without water, regardless of nitrogen treatment (Fig. 1). Intermediate levels of nitrogen amendments combined with irrigation appeared to improve biomass yields, but the improvement was not statistically significant (Fig. 1). Large-scale grasslands showed similar dependencies to water, and analysis of CRP biomass suggests that autumn yields are best correlated to June precipitation values. A linear regression line with an r^2 value of 0.30 fits a scatterplot of the yield data by June precipitation amount (Fig. 2).

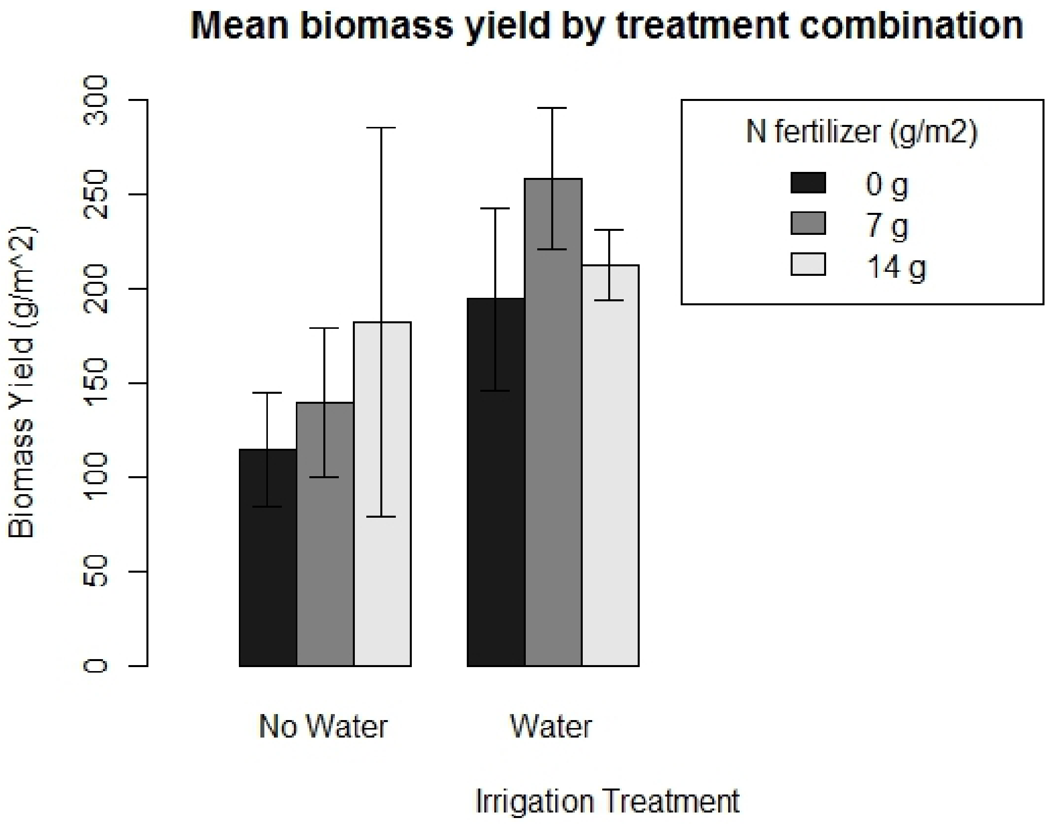

Fig. 1. Average biomass yields from prairie plots by treatment type averaged over 3 years of growth. Error bars indicate mean ± 1 SE.

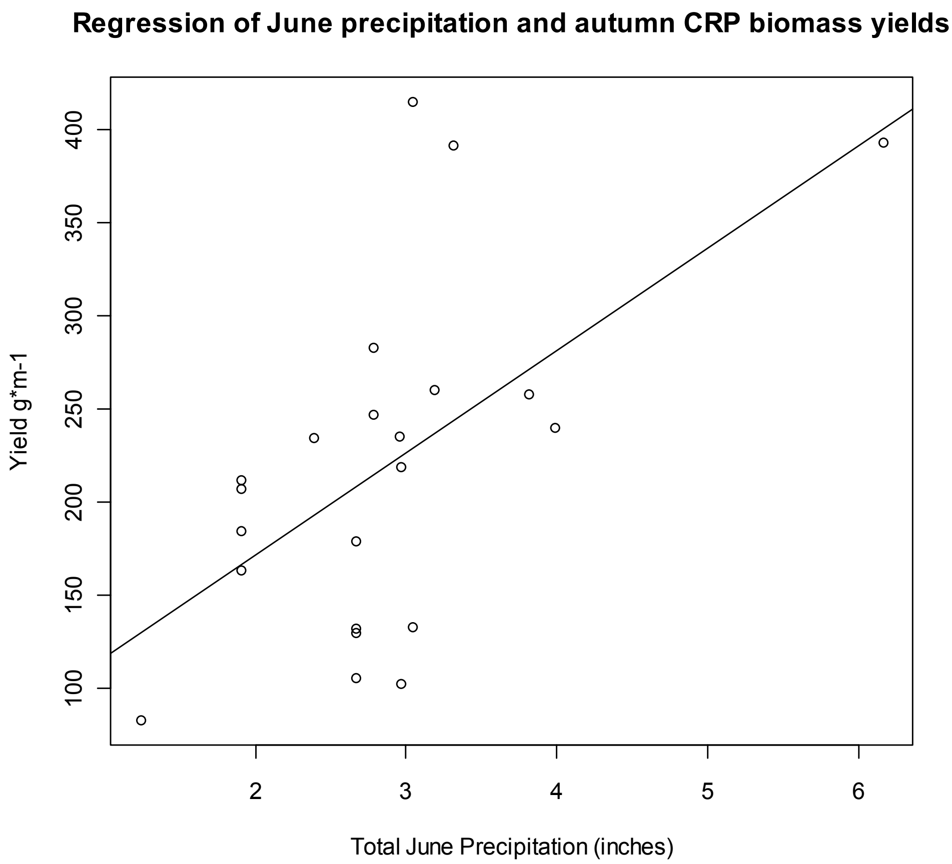

Fig. 2. Regression plot of total June precipitation values correlated to biomass yields from CRP fields in 2006 ($r^2 = 0.30$, $F_{1,20} = 10.15$, $P < 0.005$).

Table 1. *Analysis of variance table with main effects of N fertilizer and irrigation on mean biomass yields averaged from 2008–2010*

Source	DF	F ratio	*P*
Nitrogen	2	2.48	0.1
Irrigation	1	17.19	< 0.001
Residual	32		

Discussion

Results indicate that despite growing season variations, irrigation improves yields with or without N amendments. Results also suggest that biomass yeilds, averaged over multiple years, may be increased by applying a combination of internediate amounts of N with irrigation. That corresponds with expectations, but the increase was not statistically significant over the years of data available. Nitrogen alone did not consistently affect yields. This suggests that some characteristics of the growing season may influence how N interacts with prairie biomass production.

For the field-scale sites, precipitation during June was a significant predictor of autumn biomass yields, but no other single monthly precipitation total was significant. This suggests that the timing of water application may also have an important role in improving biomass yields. This observation provides evidence that prairies respond differently to water inputs depending on seasonal conditions, possibly including climate and plant phenology.

Depending on biomass markets, the costs of fertilizer, fuel prices, and other expenses, establishing an irrigation system, and annually purchasing N fertilizer may or may not be an economically feasible method of improving biomass yields. Other options include (1) strategically placing prairie bioenergy systems to intercept nutrients and water running off agricultural fields. This can provide both an increased contribution to the biomass supply and a decreased contribution to pollution; (2) Growing perennial biofuels above municipal water treatment drain fields. The remaining nutrients in wastewaters can be acquired by deep-rooting prairie plants and microbes before they reach groundwater; (3) Sewage sludge and other nutrient rich products with limited markets can safely be applied as fertilizer to these non-food crops, disposing of those products while increasing biomass production.

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