Switchgrass Lignin Regulation and Ethanol Production Cost

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Abstract

The optimal switchgrass genotype from among 250 alternatives for producing biomass for use in an enzymatic hydrolysis conversion process to produce ethanol was determined. The consequences of the selected genotype, relative to the most common commercially available variety, on ethanol production costs and on land requirements are determined.

Key words: genotype, lignin, biomass, ethanol, cost, feedstock, enzymatic hydrolysis

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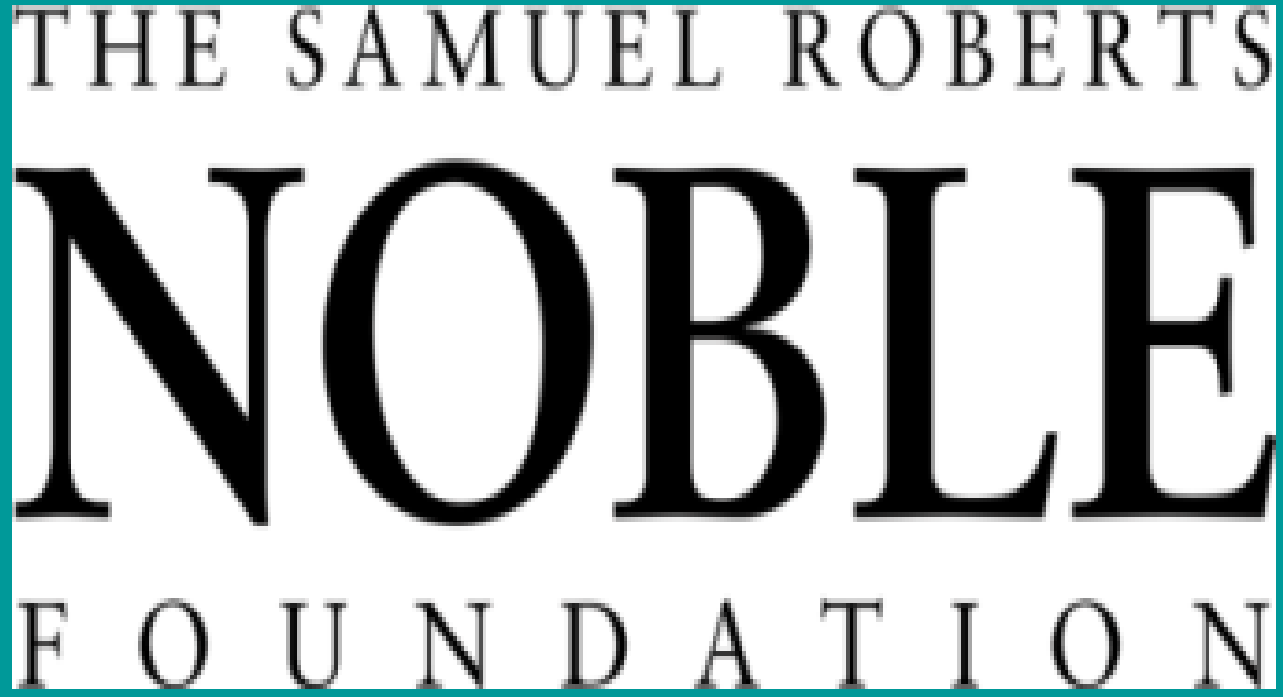
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INTRODUCTION

Switchgrass (*Panicum virgatum L.*) biomass recalcitrance to saccharification is a limiting factor for its conversion to ethanol via enzymatic hydrolysis (Chen and Dixon 2007). Conversion resistance is proportional to the lignin content. High lignin content inhibits the decomposition of cellulose and hemicellulose into sugar polymers (Shen et al. 2012).

Plant breeding may be used to produce genotypes with reduced lignin. Specific switchgrass genes may be targeted to increase the saccharification efficiency for ethanol production by reducing the cell wall recalcitrance. Studies of lignin modification have reported a strong negative correlation between lignin content and total sugar released (Chen and Dixon 2007). However, reducing the lignin content negatively affects plant growth and consequently reduces the dry biomass yield. Therefore an important aspect of the lignin genetic down-regulation in switchgrass breeding programs is the trade-off among lignin content, sugar content, and dry biomass yield. While reducing lignin content increases the sugar content and the ethanol yield per unit of dry biomass it also reduces the dry biomass yield per land unit. The reduction in dry biomass yield per hectare could offset the increase in ethanol yield per ton and lower the overall ethanol production per hectare.

To-date, lignin biosynthesis has exclusively relied on the down-regulation of the lignin monomers which affects the plant viability and therefore offers limited applications in the area of biofuel production (Li et al. 2008). The objective of the present study is to determine the optimal switchgrass genotype from among 250 alternatives for producing biomass to be used in an enzymatic hydrolysis conversion process to produce ethanol, and to compare the value of this genotype with its non modified parent genotype.

METHODS

Data were produced in a field experiment with 250 switchgrass genotypes, in three locations with two replications over two years. The sites were located near Ardmore and Burneyville, Oklahoma and Athens, Georgia. The experiment at each location was a complete randomized block design. Each replication consisted of a unique switchgrass plant of the corresponding genotype. Switchgrass biomass was harvested from individual plants and measured for fresh and dry biomass yield. Biochemical content, including lignin, xylose, and glucose content, were also measured. Theoretical ethanol yield was determined for each genotype following the sugar conversion to ethanol equation developed by Shi et al. (2009).

Modifying the lignin content will result in changes that have economic consequences. First, a reduction in lignin content is likely to be associated with a greater incidence of lodging of mature plants which will increase harvest costs either by reducing the number of harvest days or by increasing field losses. Second, a reduction in lignin content could reduce total quantity of biomass required for a biorefinery of a given size thereby reducing annual biomass to biorefinery transportation costs. Third, a reduction in lignin content could result in less waste material production by the biorefinery and reduce waste disposal cost.

A mathematical programing model is used to evaluate these consequences. The field-to-ethanol model is constructed and solved to determine the total land area required to support a fixed capacity biorefinery and total cost to produce a liter of ethanol when the non modified variety is used. The model is then solved under the assumption that the preferred genotype from among the 250 evaluated is used. The findings from the models are compared to determine the consequences of the selected genotype on total costs of producing ethanol and on the total land area required to do so. The findings are contingent on the assumption that the same number of plants could be harvested per hectare from both genotypes.

RESULTS

Expected biomass yield per plant(kg)

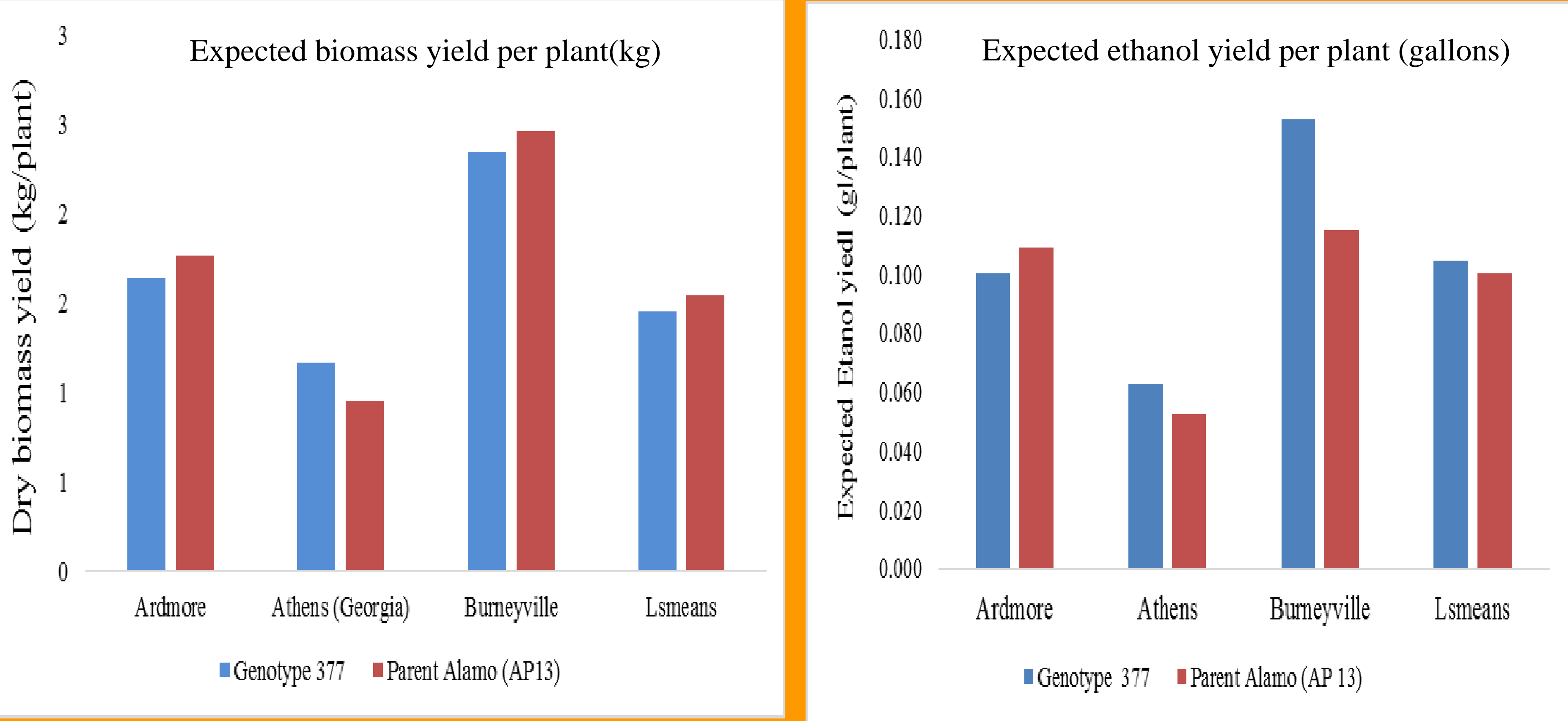Expected ethanol yield per plant (gallons)

Figure 1: Biomass Yield of two switchgrass genotypes produced in Ardmore Oklahoma and Athens, Georgia (Mg/ha)

➤ On average the parent Alamo genotype produced 8% more biomass compared to genotype 377. In Athens the difference was not significant (Pvalue < 0.001).
➤ Yield varied significantly across locations
➤ Results suggest that lignin regulation affects dry biomass yield

Table 1:Economic tradeoff associated with lignin regulation in switchgrass cultivars assuming the same number of plants per hectare.

Variable	Genotype 377 (Experimental)	Ap13 (Parent Alamo)
Lignin content (%)	24	25
Ethanol yield (gallon /Mg)	62	53
Biomass required (1000 Mg)	1,638	1, 916
Feedstock production and procurement cost (1000$)	11.208	14.502
Land requirement (1000 ha)	130	170
Transportation cost (1000$)	20	26
Storage cost (1000$)	661	774
Land rent (1000$)	714	921
Ethanol production cost ($/gallon)	3.19	3.37

➤ Lignin down regulation increases both xylose and glucose content for genotype 377 compared to the parent Alamo AP13.
➤ Lignin down regulation increases expected ethanol yield per Mg.
➤ Increasing ethanol yield reduces the quantity of biomass required and consequently the land requirement to meet the biorefinery capacity.
➤ The cost to produce ethanol declines due to lower feedstock production and procurement cost.

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CONCLUSIONS

➤ Reducing lignin content increases sugar content and ethanol yield .
➤ Lignin down regulation reduces biomass yield per unit of land.
➤ There is a tradeoff between expected biomass yield per unit of land and ethanol yield per Mg.
➤ Optimally regulating lignin monomers in switchgrass could increase the ethanol per Mg by nearly 20%.
➤ Research is on going to determine the value of switchgrass breeding programs
➤ If the economic value is determined switchgrass breeders could be expected to focus their effort not only on high biomass yield but also on plant biochemical characteristics for optimal genetic selection of native prairies grasses.

ACKNOWLEDGEMENTS

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