BIOMASS-TYPE ALFALFA

Biomass Management System Doubles Ethanol Yield

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Alfalfa has the potential to be a significant contributor to America's renewable energy future, and USDA-ARS research is helping to realize that potential. In an alfalfa biomass production system, alfalfa forage could be separated into stems and leaves. The stems could be processed to produce electricity or liquid fuel (ethanol), and the leaves could be sold as a protein supplement for livestock. One of the advantages of alfalfa over other crops to produce biomass energy is this potential for a secondary income selling the leaves as an animal feed. Therefore, concentrations and yields of leaf protein and stem cell wall sugars are key plant traits in new alfalfa varieties developed for use in biofuel production systems. In addition, cell wall lignin concentration could negatively affect pretreatment requirements and ethanol yield; so alfalfa grown for biomass should contain as little lignin as possible.

In a recent study, an alfalfa biomass energy production system was proposed where alfalfa is planted at 60% of traditional planting density and harvested only twice each growing season at late flower to early pod to maximize stem yield, enhance wildlife habitat, and reduce harvest costs. The results of the study showed that, in comparison to the traditional hay management scheme, our alfalfa biomass management scheme increased total herbage yield (Figure 1). However, it is well known that whole plant forage quality decreases with advancing maturity. Harvesting alfalfa at late flower or later may affect the forage quality of the leaves leading to a less valuable secondary product and impact the lignin content of the stems which could influence the conversion efficiency to ethanol.

A current study looks at the effects of a biomass management strategy compared to traditional hay production practices on two alfalfa entries differing in genetic origin and plant structure. MP2000 is an adapted commercial multi-leaf alfalfa cultivar selected for leafiness; it represents a typical hay-type alfalfa. ORCA-WTS (UMN 3040) is an experimental population selected from a large-stemmed Southern European cultivar for large, non-lodging, woody stems at the late-flower maturity stage; it represents what USDA-ARS proposes should be a biomass-type alfalfa. Both alfalfa entries were established in replicated trials, at two locations, in a conventional hay management treatment seeded at 42 plants per square foot and harvested three to four times each growing season (depending on the environment) at the early bud stage, and a biomass management treatment seeded at 18 plants per square foot and harvested twice per growing season at the green pod maturity stage.

Leaf Crude Protein

As expected, the average leaf crude protein (CP) concentration was greater for the hay management system (29%) than the biomass management system (24%). Averaged over harvest treatments, MP2000 had slightly higher leaf CP concentrations than ORCA-WTS (27% vs. 26%). However, because of the increases in leaf yield for the biomass production system, leaf CP yields were similar between the two alfalfa entries (Figure 1). In one growth environment, leaf CP yields were greater under the hay management than biomass management, but no differences were found between the entries for the rest of the environments tested. Biomass management may not produce the highest leaf CP yield in every environment, but could produce comparable leaf CP yields to hay management in most environments. Biomass management produced comparable leaf CP yields in 2 cuts to the total of 3-4 cuts under hay management. The reduction of harvests per season for the biomass management treatment would reduce production cost making it more profitable than hay management.

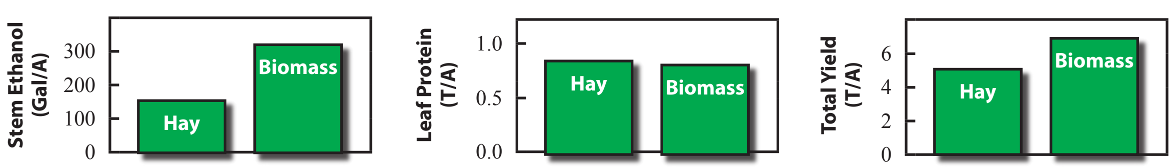

Figure 1. *Average herbage yield, leaf CP yield, and stem ethanol production of MP2000 and ORCA-WTS alfalfa under hay vs. biomass production systems.*

	Stem Cell Wall Sugars	Stem Lignin	Total Stem Sugar Yield
	% DM	% cell wall	lbs/acre
Hay Management	52.0	20.8	2635
Biomass Management	54.4	22.1	4126
$LSD_{0.05}$	0.7	0.3	515

Table 1. *Average stem cell wall lignin concentration and total sugar concentration and yield for hay and biomass harvest management system.*

	Stem Cell Wall Sugars	Stem Lignin	Total Stem Sugar Yield
	% DM	% cell wall	lbs/acre
MP2000	52.4	21.4	3108
ORCA-WTS	53.9	21.4	3556
$LSD_{0.05}$	0.3	NS	351

Table 2. *Average stem cell wall lignin concentration and total sugar concentration and yield for both alfalfa entries.*

Stem Cell Wall Carbohydrates and Lignin

As expected for more mature alfalfa, stems had higher cell wall concentrations under the biomass management system than the hay system. Biomass management increased cell wall sugars and cell wall lignin concentrations compared to hay management (Table 1). MP2000 was lower in total cell wall sugar concentration than ORCA-WTS, but cell wall concentrations of lignin were the same for the two entries (Table 2). Increasing lignin concentration negatively impacts sugar release by pretreatments and enzymatic saccharification for several biomass crops, including alfalfa stems. Data suggest that conversion efficiency should not differ between these two alfalfa entries because they did not differ for lignin concentration in the cell wall. However, alfalfa stems from the biomass management system may be more difficult to saccharify because of the increased lignification of the cell wall under this management system.

Based on the dry matter concentrations of hexose (glucose, galactose, and mannose) and pentose (xylose and arabinose) cell wall sugars of alfalfa stems (Table 2), the National Renewable Energy Laboratory's on-line theoretical ethanol yield calculator (http://www1.eere.energy.gov/biomass/ethanol_yield_calculator.html) predicts that ORCA-WTS stem material could be converted to 77.5 gallons of ethanol per ton of stem biomass compared to 74.6 gal/ton from MP2000 stems, averaged across both management systems. This represents a 4% difference in theoretical ethanol yield between these two alfalfa entries. Alfalfa stems harvested from the biomass management system could theoretically yield 6% more ethanol than the hay management system (78.4 vs. 73.7 gal/ton) across both entries (Table 1). Of course, actual ethanol yield would depend on conversion process efficiency and response to differences in lignin concentration of alfalfa from the different management systems.

Total annual stem cell wall sugar yields increased 37% under the biomass management system compared to the hay management system, and ORCA-WTS had 13% greater total cell wall sugar yield than MP2000 (Tables 1 and 2). Theoretical ethanol yield from the combination of biomass-type alfalfa, ORCA-WTS, and biomass management system was 326 gal/ac/year (Figure 1). This ethanol yield was 99% greater than the hay-type alfalfa, MP2000, (164 gal/acre/year) harvested with a typical hay management system. The differences in stem cell wall sugar concentrations for ORCA-WTS grown under the biomass management system compared to MP2000 under the hay management system only accounted for an 11% increase in theoretical ethanol yield. Therefore, it is obvious that the increased stem dry matter yield of the biomass management system, rather than the difference in stem cell wall sugar concentrations, was the driving force that accounted for the majority of enhanced ethanol yield observed for the combined biomass-type alfalfa under a biomass management system.

Study results demonstrate that development of biomass-type alfalfa with large non-lodging stems can significantly increase the potential ethanol production from alfalfa. Combining this unique type of alfalfa with a biomass management system (less dense stand and harvesting less frequently at much later maturity stages) dramatically increased stem yield and doubled the potential ethanol production. Clearly, opportunities exist for alfalfa to be a significant contributor to America's renewable energy future.