Potential for ethanol production from conservation reserve program lands in Oregon

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Increase in energy demand has led towards considering lignocellulosic feedstocks as potential for ethanol production. Aim of this study was to estimate the potential of grass straws from conservation reserve program (CRP) lands as feedstocks for ethanol production. The CRP was initiated to ensure reduction in soil erosion with a concomitant improvement in water quality and aquatic habitats. Species and abundance of various grasses in CRP sites can vary substantially. Ethanol yield from biomass is directly correlated to sugar content among other factors. It therefore becomes important to study the variability in the biomass composition from different CRP sites to reliably estimate biofuel production potential. Grass samples were collected from five fields contracted to CRP in Umatilla County in Northeastern Oregon. Composition of these samples was experimentally determined and was statistically verified to be similar for most of the sites. Sugar content was highest (60.70%) and statistically different for only one site (CRA 8.2). Our results suggest that biomass harvested from different sites did not significantly vary in terms of their chemical composition and therefore could be used in a single integrated process to produce bioethanol. Total potential ethanol yield from various CRP lands in Oregon, assuming a 10 yr harvesting frequency, was estimated to be 40×10^6 l of ethanol (28.5–53.7×10^6 l/yr) with current management practices subject to other constraints. © *2011 American Institute of Physics.* [doi:10.1063/1.3658399]

I. INTRODUCTION

Biofuels are important because they can replace petroleum fuels. Biofuels can play an important role in reducing long term greenhouse gas (GHG) emissions because renewable feedstocks have short carbon cycle compared to fossil fuels.

Ethanol produced from cereal and sugar crops is the first generation biofuel that has been commercialized. Most of the ethanol is currently produced from corn in U.S. and from sugarcane in Brazil. However, these first generation biofuels suffer from many limitations such as intensive agricultural inputs, land requirements, and food vs. fuel debate. Second generation fuels or fuels derived from lignocellulosic biomass can overcome some of the limitations of first generation fuels. Lignocellulosic biomass such as agricultural residues, forest residues, municipal waste, industrial waste paper, and dedicated energy crops can be converted to ethanol using thermo-chemical or biochemical techniques. Use of lignocellulosic biomass as feedstock for ethanol production has several advantages such as non-food feedstocks, abundant availability, and relatively lower cost.[1–4] Additionally, lignocellulosic ethanol has also been reported to have greater potential for GHG reduction and lower fossil energy use compared to first generation biofuels.

Lignocellulosic biomass feedstocks are composed of cellulose, hemicellulose, lignin, extractives, and some inorganic materials. Biomass in general typically contain 35%–50% cellulose and 20%–35% hemicellulose, and 10%–30% lignin.[5–7] Cellulose and hemicellulose can be converted to sugar monomers by hydrolysis process, which can be further fermented to ethanol.

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Lignin fraction of the biomass along with non-convertible carbohydrate fractions can be burned to produce process steam and electricity.

Generic cellulosic ethanol production process consists of size reduction of feedstocks, pretreatment, hydrolysis, fermentation, and ethanol recovery. Many pretreatment process such as dilute acid, dilute alkali, hot water, steam explosion, ammonia fiber expansion (AFEX), ammonia recycle percolation (ARP), and organosolv have been described in literature (reviewed in detail[1,4,8,9]). Hydrolysis of pretreated biomass is generally performed using enzymes due to high sugar yields, mild operating conditions, and less energy consumption compared to acid hydrolysis.[10] Fermentation of the resulting sugars can be performed in several ways such as separate hydrolysis and fermentation, simultaneous hydrolysis and fermentation, and simultaneous hydrolysis and co-fermentation.

Several technical and infrastructural challenges exist in large scale production of lignocellulosic biofuels. For example, large scale production of ethanol from dedicated energy crops such as switchgrass (*Panicum virgatum* L.) or miscanthus (*Miscanthus giganteus*) requires large scale investment in additional land and possibly water resources for large scale production. For example, using a 5 ton/acre biomass yield and 75 gal ethanol/ton of biomass, production of 30×10^9 gal ethanol would require an additional 80×10^6 acres land in agriculture. Such large scale requirement of new lands or conversion of conservation reserve program (CRP) lands into regular production is a big task.

The possibility of CRP providing biofuel feedstocks requires consideration of the program's original intent and subsequent accomplishments of the program. The original purpose of CRP was to (1) curb production of surplus commodities, (2) reduce water and wind erosion, (3) protect long-term capability to produce food and fiber, (4) reduce sedimentation and improve water quality, (5) create better habitat for fish and wildlife through improved food and cover, and (6) provide needed income support for farmers.[11] The emphasis shifted to enhancing environmental services and habitat conservation with the 1995 farm bill. With an original goal of enrolling 40 to 45×10^6 acres of highly erodible and environmentally sensitive cropland and pasture in 1985, there are now approximately 31×10^6 acres enrolled nationwide, largely east of the Rocky Mountains.[12] As of September 2010, CRP enrollment in the Pacific Northwest (PNW) (Idaho, Oregon, and Washington) totaled 2.7×10^6 acres, of which 548 010 acres were located predominately in the semi-arid north-central and north-eastern Oregon.[13,14] General statements about the effect of CRP on rural economies are problematic,[13,15] but the extent to which the program has fulfilled environmental service goals are more easily quantified. Through a combination of field research and modeling, national reductions in soil erosion on CRP land is estimated at 224×10^6 ton per year,[13] with a commensurate improvement in water quality and aquatic habitat. The value of these environmental services, including improved fish and wildlife habitat, is estimated worth \$317 million per year to downstream communities and local residents.[13]

Grasses provide the predominate cover in the western states CRP.[13] CRP essentially reestablishes missing environmental services by reestablishing perennial grasses where native prairies were converted to cropland. Enrollees in the program are encouraged, but not required, to plant native species. Consequently, the grass mixes in CRP can vary substantially, with native, introduced, or a mix of species, from one field to the next.

A defining feature differentiating CRP in the western United Sates from the rest of the country is the type of grass grown. Highly productive C4 grasses capable of producing 20 ton/ha or more, e.g., switchgrass or miscanthus, grow predominately in the summer and require abundant summer precipitation. Grasses planted in the semiarid PNW, with its Mediterranean climate of little or no rainfall from June through August, are necessarily less productive cool season or C3 grasses. The C4 grasses east of the Rocky Mountains might produce up to 10 ton per acre from a combination of multiple harvests.[16] Without irrigation or fertilization, western CRP might be expected to produce yields similar to range or unimproved pasture land: 0.37 ton per acre per year.[17]

The objective of this study was to determine the ethanol production potential of grass straws harvested from five sites in north-eastern Oregon under CRP contract. Because CRP lands typically have a mixture of grass and forb species, their impact on overall composition and ethanol production was evaluated.

II. MATERIAL AND METHODS

A. Biomass

Biomass samples were collected from CRP contract land in Umatilla County, in northeastern Oregon. According to USDA–Farm Service Agency online records in 2008, there were 156 332 acres enrolled in CRP in the county. Each site was chosen to represent one of five common resource areas (CRA) within 50 road miles of Boardman, Oregon, where an ethanol bio-refinery is expected to be located (Table I). A CRA is defined as a geographical area where resource concerns, problems, or treatment needs are similar. It is considered a subdivision of an existing major land resource area (MLRA) map delineation or polygon. Landscape conditions, soil, climate, human considerations, and other natural resource information are used to determine the geographic boundaries of a common resource area (from USDA-NRCS General Manual, Title 450, Part 401, Subpart C, 401.21). Within each field, five randomly chosen 1 m^2 plots were identified and the vegetation was clipped and separated by species. These samples were air dried and weighed.

B. Biomass composition analysis

1. Sample preparation

Biomass samples were ground in a Wiley knife mill, until the entire sample passed through the 2 mm screen in the bottom of the mill. Biomass samples were dried in hot air oven at 40 °C for 24 h. To obtain the particle size profile, the milled samples were sieved using sieve shaker (Allen-Bradley Sonic sifter) with sieve set from No. 20 (850 μm) to No. 100 (149 μm). The samples retained between sieve 20 and 80 were used for further composition analysis.

2. Moisture and ash content

Moisture and ash contents in the feedstocks were determined using gravimetric analysis. A gravimetric hot air oven method was used for determining the moisture content. Ash content was determined on the similar basis except that samples were combusted in muffle furnace at 575 ± 25 °C. Average of three replications was taken.

TABLE I. CRA and soil associated with each CRP contract site sampled.[15]

CRA	Soil	Elevation (m)	MAP[a] (m)	MAT[b] (°C)	FFD[c]
7.1 Columbia Basin—sandy Missoula flood deposits	Sagehill fine sandy loam (Coarse-loamy, mixed, superactive mesic Xeric Haplocambids)	91–396	0.15–0.25	10–12.2	135–200
7.2 Columbia Basin—silty Missoula flood deposits	Shano silt loam (Coarse-silty, mixed, mesic Xeric Haplocambids)	152–701	0.15–0.25	8.3–12.2	−120–200
8.2 Columbia Plateau—Loess Islands	Hermiston silt loam (Coarse-silty, mixed, Superactive mesic Cumulic Haploxerolls)	61–762	0.25–0.40	9.4–12.2	130–195
8.5 Columbia Plateau—Moist Yakima folds	Ritzville silt loam (Coarse-silty, mixed, Superactive mesic Calcidic Haploxerolls)	213–914	023–0.30	8.9–11.1	−130–180
8.11 Columbia Plateau—Umatilla Plateau	Condon silt loam (Fine-silty, mixed, Superactive mesic Typic Haploxerolls)	335–1219	0.25–0.38	7.2–11.1	100–165

[a]Mean annual precipitation.
[b]Mean annual temperature.
[c]Frost free days.

3. Extractives

Water and ethanol soluble extractives were determined using soxhlet apparatus and procedure as described in National Renewable Energy Laboratory (NREL) laboratory analysis protocol.[18] Water soluble materials may include inorganic material, non-structural sugars, and nitrogenous material. Ethanol soluble material includes chlorophyll, waxes, or other minor components. The removal of non-structural material from biomass is necessary prior to analysis to prevent interference with later analytical steps. In each experiment, about 5 g of biomass was placed in cellulose thimbles and two-step extraction was performed for 48 h using de-ionized water followed by 95% ethanol. After each extraction, the extractives were transferred to 200 ml volumetric flask. A subsample (50 ml) of extracted liquid was evaporated to dryness in a vacuum oven at 40 °C for 24 h. Change in weight recorded to the nearest 0.1 mg was used to calculate the amount of extractives. Average of two replications was taken.

4. Protein content

Protein content of feedstocks was calculated indirectly by measuring the amount of nitrogen in biomass. Biomass nitrogen content was measured using elemental analyzer (Costech Analytical Technologies, Inc.). Crude protein concentration was estimated as $N \times 6.25$. At least three replicates were taken for each sample for determining the average protein content.

5. Structural carbohydrates and lignin

Structural carbohydrates (cellulose and hemicellulose) and lignin contents of feedstocks were determined as per NREL biomass analytical procedure.[19] Briefly, a two-step acid hydrolysis was used to depolymerize biomass into sugars. In the first step, biomass samples were hydrolyzed using 72% (w/w) sulfuric acid at 30 °C for 1 h. After 1 h, concentration of acid was reduced to 4% by adding deionized water and samples were hydrolyzed at 121 °C for 1 h. The hydrolysis products, cellobiose, glucose, xylose, galactose, arabinose, and mannose, were determined by high performance liquid chromatography (HPLC) (Agilent Technologies) equipped with refractive index detector, a Bio-Rad Aminex HPX-87 P column, and Bio-Rad cation and anion Deashing Cartridge micro-Guard columns. $0.2\text{-}\mu\text{m}$ filtered de-ionized water was used as the mobile phase at a flow rate of 0.6 ml/min at 80 °C. Injection volume was 20 μl with a run time of 60 min.[7] Amount of each sugar was determined by a refractive index (RI) detector with the calibration of each sugar standard.

Acid insoluble lignin was determined using gravimetric analysis at 105 °C and 575 °C as per standard NREL protocols. Hydrolyzate was vacuum filtered through previously weighed filtering crucibles. The solids were rinsed with about 50-ml fresh deionized water. The solids were dried in hot air oven at 105 °C and then were combusted in the muffle furnace at 575 ± 25 °C. The amount of insoluble lignin was calculated by subtracting the ash content from weight of dry solids. The acid-soluble lignin (ASL) was calculated by measuring absorbance at 320 nm in UV-Vis spectroscope using water as blank. The total lignin content was the summation of acid-insoluble lignin and acid-soluble lignin. All analyses were performed in triplicate and were analyzed using Minitab 15 (Minitab, Inc. College Station, PA).

6. Ethanol yield

Ethanol yield from a biomass depends upon chemical composition, hydrolysis efficiency, and fermentation efficiency. Hydrolysis yield of cellulose and hemicellulose was assumed as 90% and 85%, respectively. When cellulose and hemicellulose are hydrolyzed to sugar monomers, there is 1.11 and 1.36 hydrolytic gain, respectively. Potential ethanol yield was estimated assuming 98% and 60% fermentation efficiencies for hexose and pentose sugars, respectively.

III. RESULTS AND DISCUSSION

A. Biomass yields and species composition

Above ground dry biomass was greater than expected from these semiarid lands (Table II). These values are likely larger than annual forage estimated from the soil survey,[17] because they

TABLE II. Biomass (above ground) and potential ethanol yields from CRP contract fields, Umatilla County, Oregon.

CRA site	Average (ton/acre)	Potential ethanol yield (l/ton)	Total ethanol yield/10 yr (l/acre)[a]	Ethanol yield (l/acre-yr)[a,b]
7.1	1.92 ± 0.76	271	520	52
7.2	2.09 ± 0.77	278	580	58
8.2	2.93 ± 0.46	335	981	98
8.5	3.00 ± 0.33	281	843	84
8.11	2.83 ± 0.61	280	791	79
Average	2.6	289	743	74

[a]Assuming harvest frequency of once every 10 yr.
[b]Yield determined on total area for CRA sites of 156 332 acres and assuming that each CRA represents 20% or 31 266 acres.

contain plant materials not harvested since the land was enrolled in CRP possibly up to 10 yr ago. Since the samples analyzed in the current study represent one time point during the year, a more accurate understanding of annual yields would be gained by a multi-year sampling design.

Fraction of different plant species in the samples is tabulated in Table III. The frequency of harvesting or grazing CRP vegetation was originally limited to maintain soil and water conservation. However, with settlement in 2006 of suit brought by the National Wildlife Federation, guidelines were put in place prescribing harvest dates and frequency relative to location and date of contract (USDA-FSA Notice CRP-664). The allowed frequency of CRP harvest (haying) in eastern Oregon and Washington is one in ten years. Although this frequency substantially limits the amount of harvestable biomass, the second constraint, timing of harvest, coincides with the needs of biofuel feed stock requirements. Grass hay is harvested in late May through mid-June to store its nutritive properties for forage. By deferring harvest until after primary nesting seasons ending either on 15 July or 15 August (depending on CRP contract), grasses will have senesced leaving plant material high in lignocellulosic biomass. If these grasses could be harvested and used for ethanol production, the goals of conservation, habitat, and renewable fuel production could be achieved. Because much of the land under CRP contract is not very productive for small grain production, with the right price support some landowners might find producing biofuel feedstock an attractive option with the concomitant habitat, soil, and water conservation.

TABLE III. Fraction of different grasses present in 5 feedstocks.

| CRA[a] 7.1 Species	%	CRA 7.2 Species	%	CRA 8.5 Species	%	CRA 8.11 Species	%	CRA 8.2 Species	%
Intermediate wheatgrass (*Thinopyrum intermedium*)	50	Tall wheat grass (*Thinopyrum ponticum*)	60	Bluebunch wheat grass (*Pseudoroegneria spicata*)	50	Sherman big bluegrass (*Poa secunda*)	35	Basin wildrye (*Leymus cinereus*)	85
Tumble mustard (*Sisymbrium altissimum*)	20	Downey brome (*Bromus tectorum*)	34	Downey brome (*Bromus tectorum*)	50	Bluebunch wheat grass (*Pseudoroegneria spicata*)	35	Intermediate wheatgrass (*Thinopyrum intermedium*)	15
Downey brome (*Bromus tectorum*)	20	Tarweed (*Amsinckia* sp.)	3			Alfalfa (*Medicago sativa*)	10		
Tarweed (*Amsinckia* sp.)	10	Prickly lettuce (*Lactuca serriola*)	3			Downey brome (*Bromus tectorum*)	15		

[a]Common resource area.
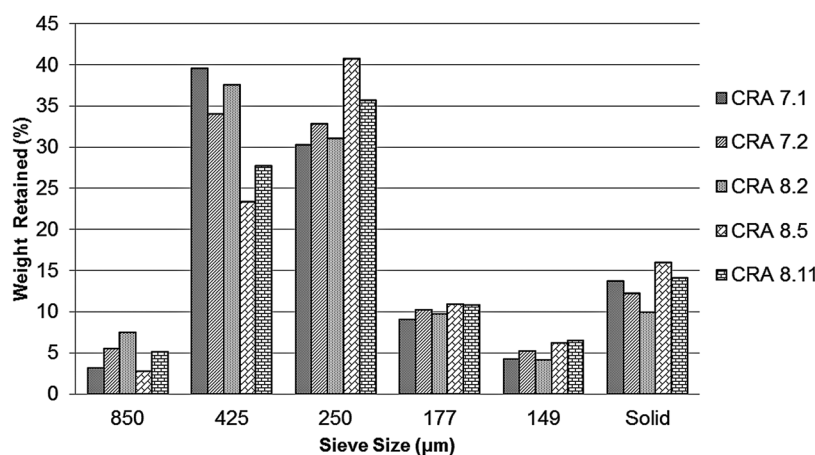
FIG. 1. Particle size profile of different feedstocks.

B. Biomass composition

The particle size profiles of the five feedstocks have been illustrated in Figure 1. About 63% to 69% of the mass was retained between the 800 and 250 μm size sieves for all feedstocks. Fraction of grasses from CRA 8.5 retained on 425 μm size sieve was lowest among all feedstocks, which indicate that the grass mix from this site was less resistant to grinding than other grasses. The feedstocks had a considerable percentage (9.9% to 16%) of fines (<149 μm), which could be a result of the fibrous nature of these feedstocks. Ash content in the feedstock varied from 7% to 12% (Table IV), which indicates significant amount of inorganic compounds in the grasses. Lignin content, a major factor that affects the hydrolysis efficiency, was found to be in the range of 13.4 to 17.45 for all grasses (Table IV). Lignin content was found maximum for grass from CRA 8.11.

Cellulose, hemicellulose, and lignin contents of all feedstocks are illustrated in Figure 2. Cellulose content in grasses was observed to be in the range of 28.8% to 36%. The xylan, galactan, arabinan, and mannan fractions considered to be part of hemicellulose, comprised of 17.94%, 19.61%, 24.67%, 20.53%, and 18.42% for CRA 7.1, 7.2, 8.2, 8.5, and 8.11, respectively. In all feedstocks, xylan was the dominant fraction (77%–89%) of total hemicellulose. Mannan was not detected in CRA 8.2 (Table V). The total structural sugars were found to be highest in CRA 8.2 (60.7%).

C. Ethanol yield

Potential ethanol yields from feedstocks were found to be 271, 278, 335, 281, and 280 l/dry ton from CRA 7.1, 7.2, 8.2, 8.5, and 8.11, respectively (Fig. 3). Among all feedstocks, ethanol yield was found maximum for grasses from CRA 8.2 due to higher sugar content (60.7%). Potential ethanol yield per acre of land from different CRP sites ranged from 520 to 981 l/acre

TABLE IV. Moisture content, ash content, protein content, and extractives (% db) of feedstocks.

| Sample name	Moisture content	Ash content	Protein content	Acid insoluble lignin (AIL)	Acid soluble lignin (ASL)	Extractives	
						Water	Ethanol
CRA 7.1	8.25 ± 0.34	6.33 ± 0.06	4.53 ± 0.60	13.69 ± 0.09	1.00 ± 0.05	16.075	2.139
CRA 7.2	9.12 ± 0.19	4.67 ± 0.15	3.66 ± 0.54	13.47 ± 0.60	0.87 ± 0.06	20.595	2.723
CRA 8.2	7.05 ± 0.60	8.53 ± 0.23	1.59 ± 0.14	13.50 ± 0.20	0.92 ± 0.03	13.875	2.341
CRA 8.5	8.34 ± 0.09	8.12 ± 0.45	1.72 ± 0.44	12.50 ± 0.51	0.91 ± 0.06	16.001	3.660
CRA 8.11	8.45 ± 0.08	9.43 ± 0.19	2.01 ± 0.64	16.24 ± 0.07	1.17 ± 0.02	10.566	3.314
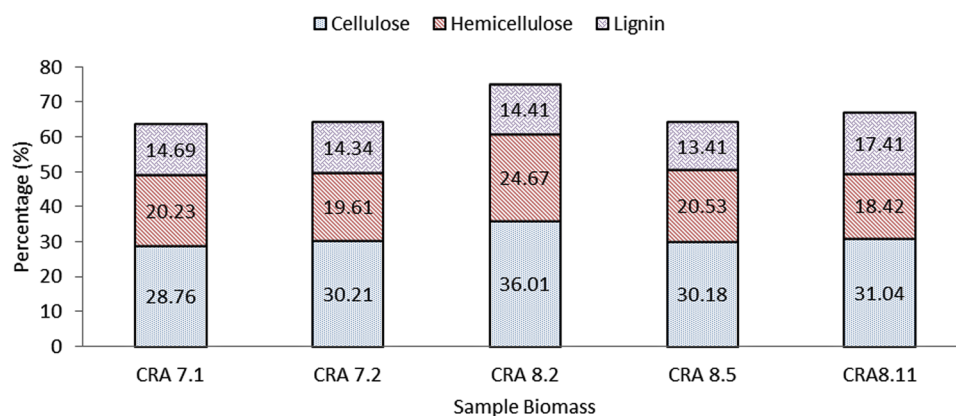
FIG. 2. Cellulose, hemicellulose, and lignin content in biomass feedstocks.

TABLE V. Structural sugars in feedstocks (% db). Numbers in the same column with same superscript are statistically similar.

Sample	Glucan %	Xylan %	Galactan %	Arabinan %	Mannan %
CRA 7.1	28.76 ± 3.05^a	16.43 ± 1.75^a	1.14 ± 0.10^a	1.93 ± 0.20^a	0.73 ± 0.02^a
CRA 7.2	30.21 ± 0.74^a	16.99 ± 0.49^a	0.97 ± 0.01^a	1.30 ± 1.08^a	0.35 ± 0.31^a
CRA 8.2	36.01 ± 0.75^b	21.98 ± 0.70^b	0.70 ± 0.06^b	2.00 ± 0.24^a	0.00 ± 0.00^b
CRA 8.5	30.18 ± 1.08^a	17.26 ± 0.51^a	0.99 ± 0.03^a	1.76 ± 0.03^a	0.52 ± 0.04^c
CRA 8.11	31.04 ± 0.61^a	14.21 ± 4.17^a	1.37 ± 0.04^c	2.05 ± 0.07^a	0.79 ± 0.07^a

(Table II). Assuming a harvest frequency of 10 yr, annual average ethanol production potential from CRA lands is 74 l/acre-yr. Extrapolating this average ethanol yield, 548 000 acres of unmanaged CRP land in Oregon have ethanol production potential of 40.7×10^6 l/yr (28.5–53.7×10^6 l/ yr). Actual ethanol potential from CRP lands would be lower due to constraints of soil erosion, harvestable yields, and transportation logistics. We speculate that this yield could be doubled if the harvesting frequency of CRP lands is reduced to 5 yr through appropriate application of herbicides and nitrogenous fertilizers. An important point to note is that actual ethanol yield from a feedstock will be dependent on many processing factors such as pretreatment method used (e.g., dilute acid, dilute alkali, steam explosion, hot water), formation of inhibitory compounds during pretreatment, and type of fermentation (e.g., simultaneous saccharification and fermentation, separate hydrolysis and fermentation, simultaneous saccharification and co-fermentation).[20–22] The
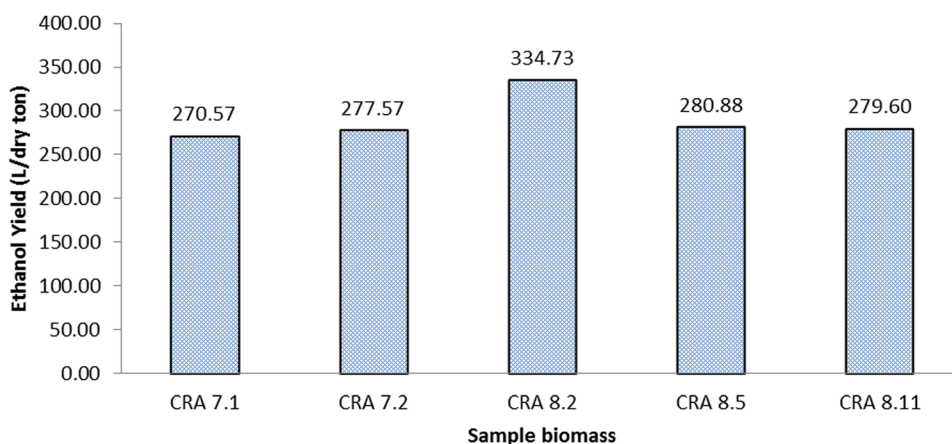

FIG. 3 Potential ethanol yields from biomass feedstocks.

purpose of this study was to estimate potential ethanol from CRP lands and hence ethanol yields were calculated based on reasonable assumptions.

IV. CONCLUSION

There is potential for harvesting limited amounts of biomass from the CRP lands for ethanol production and meeting the goals of conservation, habitat, and renewable fuel production. Because much of the land under CRP contract is not very productive for small grain production, with the right price support some landowners might find producing biofuel feedstock an attractive option with the concomitant habitat, soil, and water conservation. Grasses from CRP lands were found to contain 28.8% to 36.0% cellulose and 17.9% to 24.7% hemicellulose. Lignin content ranged from 13.4% to 17.5% within different grass mixes. Though the grass mixes from different CRP sites varied, the chemical composition of the grasses from most of the sites was significantly similar. Using the site with the highest sugar content (60.70%), maximum theoretical ethanol yield is (334.7 l/dry ton). Due to similar composition of grasses from different CRP sites, these feedstocks can be used in similar processing conditions in ethanol production plant. Given a 10 yr harvest frequency, we estimate average ethanol potential of 40×10^6 l of ethanol ($28.5–53.7 \times 10^6$ l/yr) from the 500 000 acres of CRP in Oregon under current management.

ACKNOWLEDGMENTS

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