AIP | Journal of Renewable and Sustainable Energy

Ethanol production potential from conservation buffers in the inland Pacific Northwest

John D. Williams, Dave S. Robertson, Dan S. Long, Stewart B. Wuest, Deepak Kumar, Ankita Juneja, and Ganti S. Murthy

Citation: Journal of Renewable and Sustainable Energy **8**, 053102 (2016); doi: 10.1063/1.4962414
View online: http://dx.doi.org/10.1063/1.4962414
View Table of Contents: http://scitation.aip.org/content/aip/journal/jrse/8/5?ver=pdfcov
Published by the AIP Publishing

JOURNAL OF RENEWABLE AND SUSTAINABLE ENERGY **8**, 053102 (2016)

Ethanol production potential from conservation buffers in the inland Pacific Northwest

John D. Williams,[1,a)] Dave S. Robertson,[1] Dan S. Long,[1] Stewart B. Wuest,[1] Deepak Kumar,[2] Ankita Juneja,[3] and Ganti S. Murthy[4]

[1]*United States Department of Agriculture–Agricultural Research Service, Columbia Plateau Conservation Research Center, 48037 Tubbs Ranch Road, Adams, Oregon 97810, USA*

[2]*Agricultural and Biological Engineering, University of Illinois at Urbana-University of Illinois at Urbana-Champaign, Champaign, Illinois 61801, USA*

[3]*Illinois Sustainable Technology Center, Prairie Research Institute, Champaign, Illinois 61820, USA*

[4]*Department of Biological and Ecological Engineering, Oregon State University, Corvallis, Oregon 97331, USA*

(Received 8 March 2016; accepted 25 August 2016; published online 12 September 2016)

Meeting the goals set by the Energy Independence and Security Act requires evaluation of all potential feedstock sources including arid and semi-arid portions of the western United States (U.S.). The objective of this study was to assess the lignocellulosic feedstock potential in stream buffers of the inland Pacific Northwest. A 3-yr (2010–2012) experiment was conducted at two sites within each of the three precipitation zones (low, mid, and high). At each site, barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L.), alfalfa (*Medicago sativa* L., cultivar Ladak), tall wheatgrass (*Agropyron elongatum* Podp. cultivar Alkar) (TWG), and a mix of alfalfa and tall wheatgrass (MIX) were planted in a randomized complete block experimental design. Productivity followed precipitation; in the high and mid precipitation zones, the MIX and TWG treatments showed potential production of $3{,}079 \pm 262\,\mathrm{l\,ha^{-1}}$ and $3{,}062 \pm 235\,\mathrm{l\,ha^{-1}}$. Productivity in the low zone was inadequate or unreliable as a source of feedstocks. A geographic information system was then used to identify the area available for stream buffers with soil resources that matched the experimental results within each precipitation zone. In 3.7×10^6 ha of dryland cropland, 44 656 ha (1.5%) available within the mid and high precipitation zones is capable of producing 147 million liters of ethanol. This potential contribution is 0.3% of the lignocellulosic ethanol production expected by the year 2022. Though not a substantial contribution, the added benefit of producing energy for on-farm consumption might provide an additional incentive for landowners and managers to install conservation buffers.
[http://dx.doi.org/10.1063/1.4962414]

I. INTRODUCTION

The Title II, Energy Security in the Energy Independence and Security Act (EISA) of 2007, required an accounting of lignocellulosic feedstocks to increase the production of biofuels.[1] The goals set by EISA called for 3.79 Gl of biofuel to be produced from lignocellulosic feedstocks by 2013, 6.62 Gl by 2014, and 60.57 Gl by 2022.[1] In practice, only 0.28 million liters (ML), or 0.007% of that called for by EISA, were produced in 2013.[2] The causes for this shortfall are numerous, spanning economic, political, and technical issues. However,

[a)]Author to whom correspondence should be addressed. Electronic mail: john.williams@ars.usda.gov

commercial scale production of lignocellulosic ethanol was expected to begin in 2014,[3] east of the 100th meridian.[3] Research and development have concentrated there because of abundant precipitation ($\geq$510 mm) per year, fertile soils, highly productive plant communities, and thus, an abundant supply of raw materials.[4–6]

In the west of the 100th meridian, particularly in the northwestern inter-mountain region between the Cascade and Rocky Mountain ranges, biomass productivity is limited by low precipitation and soil fertility. Dryland crop agriculture in this region is limited to an extent, with the exception of the interior Pacific Northwest (PNW) where native shrub-steppe transitions into prairie. With a Mediterranean climate characterized by fall, winter, and spring precipitations with cool temperatures followed by dry, hot summers, the conditions are ideal for C_3 perennial and annual small grain (SG) grasses. These conditions, combined with low mean minimum temperatures (8–10 °C) during active growth, are limiting for the C_4 grasses, e.g., switchgrass (*Panicum virgatum* L.) or Miscanthus (*Miscanthus* sp.) typically considered for lignocellulosic feedstock.[7–10] Whereas productive stands of C_4 grasses can be grown on millions of hectares east of the 100th meridian including on marginally productive land,[11] C_3 grass productivity is relatively low across the intermountain west, particularly in land enrolled in various conservation reserve programs. These former croplands have soils that are either drought or saline affected, sometimes shallow and rocky, and are often difficult to harvest because of steep terrain. Consequently, the crop biomass produced there is not abundant enough to warrant harvesting, except perhaps by grazing livestock.

Adequate production to warrant harvesting for lignocellulosic feedstock in the PNW might exist in waterways and streams with perennial grass buffers. Plant material typically considered forage, e.g., grasses, forbs, legumes, is generally considered a secondary, supplemental source of lignocellulosic feedstock compared to materials not seasonally limited in abundance.[5,12] As a supplemental source, annual or semi-annual harvests might be possible without damaging ecosystem functions such as filtering sediment from overland flow and nutrients from the vadose zone.

Early national estimates for biofuel production from agriculture were based on the USDA—National Resource Inventory, a county by county reporting of land use acreage and agricultural production.[11,13] Our objective was to provide a physically based estimate of biofuel lignocellulosic feedstock production, specifically from multi-species stream buffers as they are planted in the dryland cropping regions of northern Oregon, central and eastern Washington, and northwestern Idaho. Stream buffers installed in production fields occupy the part of the landscape formally populated with riparian vegetation, are the most productive areas in the arid and semiarid PNW,[14] and have the greatest potential to produce sufficient biomass to make harvest feasible. Based on the values obtained for lignocellulosic production by Williams *et al.*,[15] we compared the productivity of these sites to the productivity reported in the published literature for other areas growing grass feedstocks, and estimated the potential ethanol production in stream buffers across the inland PNW precipitation gradient.[16,17] Finally, we estimated the areal extent on which these feedstocks could be grown and potential ethanol production based on the potential buffer areas defined by the range productivity mapped in the county level surveys produced by the United States Department of Agriculture–Natural Resource Conservation Service (NRCS).

II. MATERIALS AND METHODS

A. Research location

We established six research sites with simulated 50 m stream buffers in areas adjacent to croplands in 2008. Dryland agriculture conditions and practices in the interior PNW fall within in three precipitation zones, low <300 mm yr^{-1}, mid 300–450 mm yr^{-1}, and high >450 mm yr^{-1}.[16,18] Two sites were located along intermittent or ephemeral stream channels within each of these precipitation zones (Table I).

Sites were located within the low and mid zones in northeastern Oregon and within the high precipitation zone in east-central Washington (Figure 1).

TABLE I. Research sites in the dryland cropping area of the inland Pacific Northwest used to determine the lignocellulosic productivity for biofuel feed stock.[19,20]

Site[a]	Location	MAP zone (mm)[b]	MAT (°C)[c]	Elevation (m)	Measured MAP (mm)[d]	Soil[e]
L1	N45°40′09″, W119°08′01″	<300	9.4–11.7	268	277 ± 143	Kimberly fine sandy loam (Coarse-loamy, mixed, mesic Torrifluventic Haploxerolls)
L2	N45°55′00″, W118°49′20″	<300	9.4–11.7	431	305 ± 80	Hermiston silt loam (Coarse-silty, mixed, superactive, mesic Cumulic Haploxerolls)
M1	N45°51′14″, W118°39′31″	300–450	9.4–12.2	538	338 ± 77	Onyx silt loam (Coarse-silty, mixed, mesic Cumulic Haploxerolls)
M2	N45°49′55″, W118°37′55″	300–450	9.4–12.2	523	336 ± 78	
H1	N46°47′07″, W117°04′31″	>450	7.2–8.9	794	565 ± 23	Thatuna silt loam (Fine-silty, mixed, mesic Xeric Argialbolls)
H2	N46°45′41″, W117°11′38″	>450	8.3–10.6	766	565 ± 23	Latah silt loam (Fine, mixed, superactive, mesic Xeric Argialbolls)

[a]Site/precipitation zones based on mean annual precipitation (MAP). L = low, M = mid, and H = high.[21]
[b]MAP, Mean annual precipitation.
[c]MAT, Mean annual temperature.
[d]Measured mean annual precipitation and 95 percent confidence interval measured from 2009 to 2012, with an exception of L1 where record keeping ended in 2001. Records were only available from one location in the high precipitation zone.
[e]Source: http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm (accessed February 27, 2016).

B. Crop production

Crop production in this region is on a plateau shaped by the sheet flows of Columbia River Basalt and subsequent fault development. River and stream networks developed on this dissected surface and in the overlying loess deposits. Cultivation for crop production eliminated the riparian habitat in the low gradient streams, with crops planted across ephemeral and intermittent channels, and up to the edge of flowing water in perennial streams. A century of

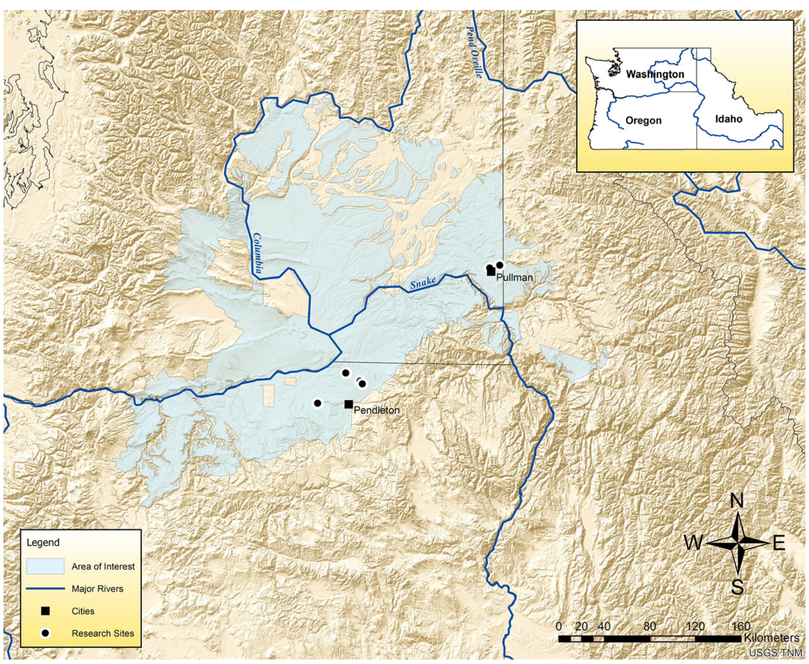

FIG. 1. Pacific Northwest inland dryland cropping region.

farming practices that led to highly erodible soil and rapid runoff created incised stream channels; when not filled by cultivation, vary in depth from 1 m to 3 m.

We established stream buffers on abandoned terraces adjacent to incised stream channels in five of six sites. At the sixth site, located in the high precipitation zone, plots were established in a wet meadow beside a zero-order intermittent channel. Soils are derived from loess parent material (Table I) with a particle size distribution consisting of sandy loam at the driest site and silt loam at the other five sites.[19,20] This region has a semiarid Mediterranean climate with 70% of mean annual precipitation falling between November and April within each precipitation zone.

We evaluated four treatments: (1) small grains (SG) barley (*Hordeum vulgare* L.) or wheat (*Triticum aestivum* L.), (2) alfalfa (ALF) (*Medicago sativa* L., cultivar Ladak), (3) tall wheatgrass (TWG) (*Agropyron elongatum* Podp., cultivar Alkar), and (4) and a mix of alfalfa and tall wheatgrass (MIX). Because these sites represent areas that once were or still are in small grain production, small grain systems appropriate to each precipitation zone were included as treatments to serve as a comparison to traditional management productivity. In the low and mid precipitation zones, the treatment was winter wheat—summer fallow (a two year rotation), which is typical for northeastern Oregon. In the high precipitation zone where annual small grain cropping is typically practiced, the treatment was a rotation of winter wheat and spring barley. We chose alfalfa and tall wheatgrass for the perennial crop treatments because the former is commonly grown in the valley bottoms of this region for forage and the latter has been recognized as adapted to and productive in the intermountain region.[22,23] Tall wheatgrass is recommended for rehabilitation of riparian and wetland areas and commonly used in conservation buffers in the intermountain west[24] and has potential as a lignocellulosic feedstock.[25] The mix of alfalfa and tall wheatgrass was included to determine if the alfalfa would enhance tall wheatgrass productivity. Site preparation and plot management details are presented by Williams *et al.*[15]

Lignocellulosic feedstock biomass in the perennial plots was mechanically harvested one time each year; September of 2010, September and October of 2011, and August and September of 2012. This harvest schedule was meant to maximize the conservation benefits for wildlife, particularly avian nesting, rearing, and fledging requirements. Samples were weighed in the field and subsamples of that material returned to the laboratory, oven dried at 65 °C for 48 h, and weighed. Potential ethanol production was determined by multiplying the sum of the calculated feature areas for each precipitation zone times harvested dry biomass times the liters-per-dry-matter values determined by Kumar *et al.*[17] for TWG and ALF. Because the MIX treatment was not specifically evaluated for liter-per-dry-matter, ethanol yield was based on the conversion and dry matter species-to-species ratios. Although not as stringent an estimate as that provided by Kumar *et al.*,[17] ethanol yields from mixed species feedstocks have been shown to produce negligible differences from homogeneous feedstocks relative to their differences in dry matter yields.[26]

C. Experimental design and data analysis

At each site, the different crop treatments were planted into 3.8 m × 50 m plots in a randomized complete block (RCB) design with four replications (Figure 2). Biomass data were analyzed using a generalized linear mixed model (GLM) analysis of variance (ANOVA).[27–29] Significant differences among treatments were accepted at $P \leq 0.05$. Data were tested for assumptions of normality using quantile-quantile plots and transformed as necessary. Data were evaluated to determine whether they fit a Poisson distribution and adjustment made to the GLM as recommended by Gbur *et al.*[29] Mean separation was conducted using least square means and Tukey tests.

D. Area calculation for biomass production

Using the best information available for the interior PNW, NRCS soil surveys,[19,20] we then identified the extent of the areas similar to where our research plots were located to develop an estimate of regional conservation buffer biofuel feedstock production. We assumed that areas

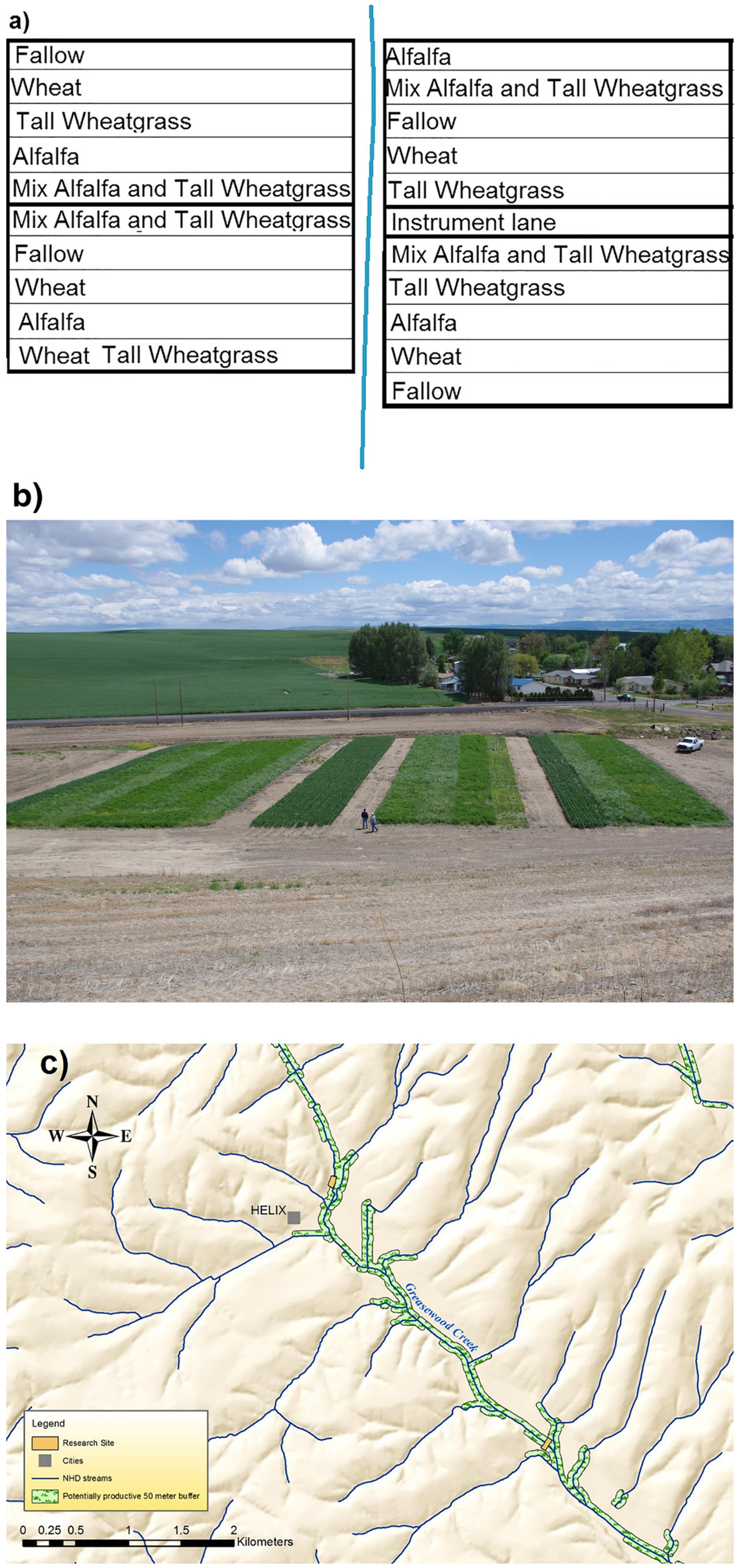

FIG. 2. (a) Plot layout and treatment distribution accomplished at site 2 in the mid precipitation zone, (b) photo of site 1 in mid precipitation zone representative of five of the six sites where all plots were distributed on one (near) side of the stream channel, and (c) location and layout of research sites in the mid precipitation zone within high production stream buffers.

mapped with the same soil types and precipitation were capable of producing biomass quantities equal to the values we recorded in our test plots in accordance with the estimates of forage availability that have been made for western rangelands. The normalized difference vegetation index (NDVI) derived from remote sensing data is useful for estimating biomass, but would be problematic for identifying similar areas because of the mix of management types adjacent to these stream channels, where the management varies from active crop production (predominately small grains alternating with fallow) to abandoned ground given over to weeds and to marginally managed conservation buffers.

Using the ModelBuilder environment in the ESRI ArcGIS Desktop 10.3 geographic information system (GIS) software package, a methodology for defining potential buffer areas was developed (Figure 3). Features containing typical dryland crops for the region were selected from the United States Department of Agriculture–National Agricultural Statistics Service (NASS) Cropland Data Layer (CDL) for the year 2012 and included in the area of interest (AOI) for analysis. These features combine satellite imagery with the extensive ground reference data.[30–34] A generalized AOI was obtained by associating predominant areas of agriculture of dryland crops in the NASS 2012 CDL with specific units of the US Environmental Protection Agency (EPA) level IV ecoregions.[35] Ecoregions included in this analysis were Palouse Hills, Okanogan Drift Hills, Loess Islands, Yakima Folds, Pleistocene Lake Basins, Deep Loess Foothills, Nez Perce Prairie, Dissected Loess Uplands, Umatilla Plateau, and Grassy Potlatch Ridges. Excluded from the analysis were Native American Indian lands, military installations

FIG. 3. Work flow GIS process model used to estimate available area for perennial lignocellulosic biofuel production in each of the three precipitation zones in the interior Pacific Norwest dryland crop production region.

such as the Yakima Training Facilities, the Hanford Nuclear Reservation, National Wildlife Refuges areas, and the Channeled Scablands.[36]

Stream length features within the region were obtained from the USDI-GS national hydrography dataset (NHD)[37] high resolution (1:24 000 or higher) flowlines. The soil data layer was obtained for the following county soil surveys:[38] (in Idaho) Idaho, Lewis, Nez Perce, and Latah; (in Oregon) Gilliam, Morrow, Sherman, Umatilla, and Wasco; (in Washington) Adams, Asotin, Benton, Chelan, Columbia, Douglas, Franklin, Garfield, Grant, Kittitas, Klickitat, Lincoln, Spokane, Walla Walla, Whitman, and Yakima. The county soil survey databases and associated soil survey geographic database (SSURGO) level (1:24 000) mapping were used in conjunction with the NRCS soil data viewer (SDV, v.6.1).[13] The SDV was developed by NRCS to allow the end users to build and interpret thematic maps based on the data within more than 50 tables of each county soil database. The NRCS defines rangeland productivity in terms of favorable, normal, and unfavorable years. To provide a conservative estimate of production, a lower limit of 1.12 Mg ha^{-1} was first used to identify the potential stream buffers in an unfavorable year. We reduced this value to 1.01 Mg ha^{-1} to remove the production value differences found at state and county boundaries (soil survey boundaries) for the same soil types with shared values.

Average annual precipitation values for the AOI were obtained using the data from the parameter-elevation relationships on the independent slopes model (PRISM) developed by climate group website.[39] The average annual precipitation 800 m gridded data layer obtained from the PRISM Climate Group was derived from a 30 year record from 1981 to 2010.

Flowline features and rangeland productivity threshold features were clipped to the AOI. The 30 year normal precipitation raster was extracted to the AOI and converted to polygon features representing each precipitation zone. Flowlines were buffered 50 m independently to the left and right, and clipped to the productivity threshold features. The remaining left and right buffers were cleaned using interior buffering to eliminate features with widths less than 50 m. A minimum production area of 1 ha was used to remove the small buffer areas that might be too small to be suitable for production purposes. The remaining left and right buffers were merged. The potential stream buffers were then clipped to each precipitation zone and the area determined. Uncertainty associated with the precipitation regime boundaries derived from the 800 m PRISM raster was conservatively quantified. The buffer tool was used to define an area of 800 m adjacent to the mid precipitation boundary. The area of proposed conservation buffer strip that fell within the precipitation zone boundary area of uncertainty was calculated and used to express a range of possible production.

III. RESULTS

Treatments TWG and MIX produced significantly more lignocellulosic feedstock than ALF and SG, with the largest treatment differences in the mid and high precipitation zones (Figure 4). There was no statistical difference in production between TWG and MIX, or between ALF and SG. In the high and mid precipitation zones, TWG and MIX produced between 8.24$\pm$ Mg ha^{-1} and 10.7 $\pm$ 0.8 Mg ha^{-1} dry biomasses, with significantly lower values from plantings in the low precipitation zone and ALF and SG in all precipitation zones.

Based on the conversion rates determined by Kumar *et al.*,[17] the best ethanol production potential was from the TWG in the high precipitation zone (3079 $\pm$ 262 l ha^{-1}) and the MIX in the mid zone (3062 $\pm$ 235 l ha^{-1}) (Table II). Within treatments, TWG and MIX were significantly more productive in the mid and high precipitation zones than in the low precipitation zone, whereas ALF and SG were not statistically different among the precipitation zones (Table II). Within each precipitation zone, TWG and MIX were significantly greater than ALF and SG treatments (Table II). Combining alfalfa and tall wheatgrass in the MIX treatment did not improve the potential ethanol productivity (Table II).

There are approximately 77 504 stream km in the rainfed cropland of the interior PNW. Along these streams, we identified a total of 55 120 ha meeting our criteria for 50 m streamside buffers and lignocellulosic feedstock production. Taking into account the uncertainty associated with the precipitation zone boundaries, the areas available for production in each

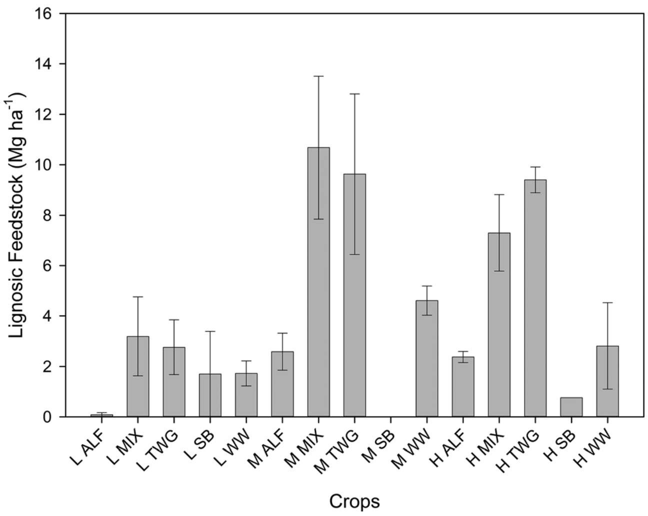

FIG. 4. Mean and standard errors for lignocellulosic production from across three precipitation zones of the inland Pacific Northwest.[15] L is the low precipitation zone, M is the mid precipitation zone, and H is the high precipitation zone. ALF is the alfalfa, MIX is the alfalfa and tall wheat grass mixture, TWG is the tall wheatgrass, SB is the spring barley, and WW is the winter wheat.

of the three precipitation zones are dry (10 464 ± 704 ha), mid (20 963 ± 1916 ha), and high (23 693 ± 1221 ha). In the mid and high precipitation zones where the productivity is the most promising, there are 47 753 stream km or 44 656 ha that meet our criteria. These areas represent 1.1% and 2.4%, respectively, of the area in the mid and high precipitation zones.

The highest potential production of ethanol obtainable was from the biomass in the mid and high precipitation zones with the highest producing treatments MIX and TWG. Using the mid-range areas estimates applied to MIX and TWG, potential production of ethanol varied from 62.91 ± 5.37 ML in the MIX treatment to 72.95 ± 6.21 ML in the TWG treatment per year (Table III).

IV. DISCUSSION

The sites in the mid and high precipitation zones where we recorded the highest production values were adjacent to ephemeral channels. Productivity of TWG and MIX in the mid and high precipitation zones met or exceeded the 9.4 Mg ha^{-1} level needed to attract the producer's interest.[40] On a per unit area basis, dry biomass production of TWG and MIX in the mid and high precipitation zones compares favorably with the rainfed feedstocks grown in other regions of the northern hemisphere, i.e., the U.S. and Europe (Table IV). The combined potential ethanol production from the mid and high precipitation zones, based on the mid-range areas, is

TABLE II. Treatment mean and standard error ethanol production per hectare at six sites, two sites within each of the three precipitation zones of the inland Pacific Northwest.

Treatment[a]	Precip. zone[b]	Ethanol (l ha^{-1})[c]	Precip. zone	Ethanol (l ha^{-1})[c]	Precip. zone	Ethanol (l ha^{-1})[c]
ALF	Low[a]	19 ± 182[a]	Mid[a]	549 ± 174[a]	High[a]	467 ± 178[a]
MIX	Low[a]	1057 ± 270[b]	Mid[b]	3062 ± 235[b]	High[b]	2354 ± 240[b]
SG	Low[a]	468 ± 228[a]	Mid[a]	1464 ± 206[a]	High[a]	490 ± 266[a]
TWG	Low[a]	1038 ± 296[b]	Mid[b]	3001 ± 256[b]	High[b]	3079 ± 262[b]

[a]Treatments: ALF is the alfalfa, MIX is the alfalfa and tall wheatgrass, SG is the small grains (winter wheat, spring wheat, spring barley), and TWG is the tall wheatgrass.
[b]Precipitation zone. Different letters in rows indicate significant differences in same treatments between precipitation zones at $P \leq 0.05$.
[c]Different letters in columns indicate significant difference between treatments within precipitation zones at $P \leq 0.05$.

TABLE III. Potential ethanol production of four crops in three precipitation zones of the inland Pacific Northwest.

Precipitation zone[a]	Treatment[b]		Dry area estimate	Mid-range area estimate	Wet area estimate
				Ethanol (ML)	
Low	ALF	a	0.19 ± 1.78	0.20 ± 1.90	0.21 ± 2.03
	MIX	a	10.32 ± 2.64	11.06 ± 2.83	11.80 ± 3.02
	SG	a	4.57 ± 2.23	4.90 ± 2.39	5.23 ± 2.55
	TWG	a	10.13 ± 2.89	10.86 ± 3.10	11.59 ± 3.31
		a			
Mid	ALF	b	10.46 ± 3.31	11.51 ± 3.65	12.56 ± 3.98
	MIX	a	58.32 ± 4.48	64.19 ± 4.93	70.05 ± 5.38
	SG	b	27.89 ± 3.92	30.69 ± 4.32	33.49 ± 4.71
	TWG	a	57.16 ± 4.88	62.91 ± 5.37	68.66 ± 5.86
		b			
High	ALF	a	10.49 ± 4	11.06 ± 4.22	11.63 ± 4.43
	MIX	b	52.9 ± 5.39	55.77 ± 5.69	58.65 ± 5.98
	SG	a	11.01 ± 5.98	11.61 ± 6.30	12.21 ± 6.63
	TWG	a	69.19 ± 5.89	72.95 ± 6.21	76.71 ± 6.53

[a]Precipitation zones are <300, 300–450, and >450 mm, respectively.
[b]Treatments: ALF is the alfalfa, MIX is the alfalfa and tall wheatgrass, SG is the small grains (winter wheat, spring wheat, spring barley), and TWG is the tall wheatgrass. Different letters in the columns indicate significant difference between treatment means within precipitation zones at $P \leq 0.05$. Standard errors are based on treatment sample collected within each precipitation zone.

approximately 145 ML (mid MIX + high TWG). This volume is 0.3% of the 60×10^9 l lignocellulosic ethanol production mandated by the year 2022.[1]

Why, then, should we consider this resource? Despite the promising productivity of the TWG and MIX treatments, the use of the material grown in stream buffers for biofuel in this region faces a number of challenges. Those challenges are: (1) available facilities to process lignocellulosic feedstocks, (2) continuity of land ownership/management, and (3) current law concerning use of materials from federally contracted buffer zones. The answer to this question lies within our ability to address these challenges.

The first challenge can be addressed by development of small scale processing technology. At present, there is one industrial scale ethanol facility in this region located near Boardman, Oregon that processes lignocellulosic feedstocks (poplar trees and irrigated crop residues) obtained from local farms. The highly productive buffer sites that we identified in the mid and high precipitation zones are all >80 km (50 mile) outside the radius within which costs and energy required for feedstock transportation remain economical.[41] An alternative method of alcohol production might be sub-regional, i.e., small on-farm processing facilities.[41–44] Although practical implementation of this technology has yet to be realized, material grown in stream buffers (30×10^6 Mg) would be a substantial contribution to the 3.2×10^6 Mg small grain straw feedstock theoretically available after leaving enough straw to maintain soil organic matter.[45] The counties with the most available residue identified by Banowetz *et al.*[45] are located in the mid and high precipitation zones of the region. A word of caution, however, is required in considering small grain residue availability in this region. Huggins *et al.*[46,47] reported that even in the high precipitation zone of this region the removal of crop residues for any purpose (biofuel feedstock, livestock forage and bedding, or mushroom production) can have negative consequences on maintenance of soil organic carbon, soil nutrient levels necessary for crop production, and soil erosion rates. The sustainable removal of crop residues depends on cropping methods and frequency. Three crops, three year rotations produced using no-tillage are the most nearly sustainable, but are only feasible in the high precipitation zone and even there are not practiced by all the producers.

TABLE IV. Lignocellulosic feedstock production across North America and Europe in relation to productivity found in conservation buffers in the Pacific Northwest, U.S. Adapted from Sanderson and Adler.[62]

Comparison Locations	Crop	Range of recorded values (Mg ha^{-1})		Mean feedstock (Mg ha^{-1})	Citation
Northern Florida USA harvested for 2 yr[a]	Napiergrass			46.3	48
Georgia USA for harvested 3 yr[a,b]	Bermudagrass	12.8	19.9	15	49
Indiana USA harvested for 3 yr[a]	Reed canarygrass	9.4	10.1	10	50
Denmark harvested for 3 yr[a]	Miscanthus	1.4	18.2	9.1	51
Iowa USA harvested for 5 yr[a,b]	Reed canarygrass	5.5	10.2	7.7	52
Seven northeastern states USA[b]	CRP[c]	2.5	6	6.6	53
South Dakota USA harvested for 4 yr[a]	Prairie cordgrass	4.6	8.6	6.4	54
Southern Iowa USA[b,d]	Pasture on marginal land	0.8	8.2	4.2	55
Minnesota USA[a]	High-diversity prairie	…	…	3.7	56
Nebraska, South Dakota, North Dakota USA harvested for 5 yr[a,d]	Switchgrass	5.2	11.1	…	57
Minnesota USA harvested for 2 yr[a,b]	Alfalfa	7	12	…	58
Nine states in the eastern USA[a,d]	Eastern gamagrass	6.5	15.9	…	59
Northeastern Oregon, USA[e]	wheat straw	…	…	3.8	60
Low precipitation zone, PNW USA harvested 1 yr[a,b]	Upland CRP	2.7	6.1	4.5 ± 0.2	61
Mid precipitation zone, PNW USA harvested 1 yr[a,b]	Upland CRP	5.0	7.7	6.5 ± 0.1	61
Mid precipitation zone, PNW USA harvested 3 yr[a,b]	Mix	4.1	22.7	10.7 ± 0.8	
High precipitation zone, PNW USA harvested 3 yr[a,b]	Tall Wheatgrass	1.1	26.4	9.9 ± 0.8	
Mid precipitation zone, PNW USA harvested 3 yr[a,b]	Tall Wheatgrass	1.8	20.6	9.6 ± 0.8	
High precipitation zone, PNW USA harvested 3 yr[a,b]	Mix	0.9	8.7	8.2 ± 0.8	
Mid precipitation zone, PNW USA harvested 3 yr[a,b]	SG	0	18.8	4.6 ± 0.7	
Low precipitation zone, PNW, USA harvested 3 yr[a,b]	Mix	0	16.3	3.7 ± 1.0	
Low precipitation zone, PNW USA harvested 3 yr[a,b]	Tall Wheatgrass	0	11.9	3.3 ± 1.0	
Mid precipitation zone, PNW USA harvested 3 yr[a,b]	Alfalfa	0	8.3	2.6 ± 0.8	
High precipitation zone, PNW USA harvested 3 yr[a,b]	Alfalfa	0.9	2.9	2.2 ± 0.8	
Low precipitation zone, PNW, USA harvested 3 yr[b]	Rangeland	0	7	1.8 ± 2.0	
High precipitation zone, PNW USA harvested 3 yr[a,b]	SG	0	5.7	1.6 ± 0.8	
Low precipitation zone, PNW USA harvested 3 yr[a,b]	SG	0	2.2	1.5 ± 0.7	
Low precipitation zone, PNW USA harvested 3 yr[a,b]	Alfalfa	0	2.2	0.1 ± 0.9	

[a]Experimental plots.
[b]Distributed over range of sites within region.
[c]Conservation reserve program.
[d]Field scale.
[e]Estimates based on USDA-ERS records or USDA-NRCS soil survey.

There has been considerable success in establishing the stream buffers in the semi-arid croplands of the PNW, nearly 1288 km or approximately 57 870 ha, since 1999 in Washington,[63] and 8754 ha (stream lengths not reported) in the rainfed cropland of northeastern Oregon.[64] Although some of this contracted ground would overlap with the areas we identify, there remains approximately 46 466 km of stream length where buffers have not been but could be installed for biomass production. Annual harvest of perennial biomass from these buffers leaves substantial biomass for protection against raindrop impact and filtering of overland flow[15] and has the potential of aiding in the maintenance of the species composition of the buffer.[23]

Despite this availability, there remains the second challenge, which is the continuity of land ownership/management. Even for the small operation on farm facilities, efficient and economical operation will require contiguous stream buffers as sources of feedstock. In 2007, 29% of U.S. farmland was owned by non-operators, who also owned 77% of the rented farmland.[65] Mixed land ownership may result from the individuals trading rural for (sub)urban lifestyles, after which they may or may not relinquish their decision making to managers or family members remaining on the land. For instance, ownership of the 2.2 km long conservation buffer sampled by Williams *et al.*[23] was shared by five families, albeit managed by a single, conservation minded manager. But as the land is sub-divided amongst decedents of the original owners, decision making becomes more of a distributed process wherein some of the owners may have limited knowledge of farm management or conservation. Non-operators tend to be older, less likely to live on the farm, and less likely to participate in conservation programs,[65] less likely to want to be restricted by regulation,[66] and concerned about the contract lengths limiting their management options.[65]

Land enrolled in the conservation programs would be expected to contribute lignocellulosic feedstock to meet the goals originally set out in EISA,[11] including land enrolled in waterway or stream buffers.[67] These areas should prove to be sufficiently productive to help meet these goals, the third challenge can be addressed by requiring legislative action to make changes in Public Law 106-78, Section 769, which currently prohibits the harvest of federally contracted conservation buffers and riparian forests for biofuel. Thus under current conditions, the establishment of stream buffers with the dual purpose of conservation and biofuel production would necessarily be the sole responsibility of the landowner or manager. Gaining feedstock for biofuel production to reduce farm operation costs could be the necessary incentive for owners concerned about restrictive contracts, but with a desire to increase their conservation efforts by reducing soil loss and stream sedimentation from fields and overbank flows, increasing infiltration of overland flow from fields, and providing avian or wildlife habitat. A thorough cost-benefit analysis would be required, but the resource, especially compared to the availability of wheat straw, is there and abundant to make a contribution to biofuel production.

V. CONCLUSION

Results from this study show that dry matter production rates in the mid and high precipitation zones of the inland, rainfed croplands of the PNW compare favorably to other regions where lignocellulosic biofuel feedstocks are grown. Although ethanol production from our estimated 44 656 ha of suitable land only contributes 0.3% of the 2022 goals set for lignocellulosic biofuel production, the value added to conservation buffer installation could be the incentive needed for the increased installation of conservation buffers in this region.

ACKNOWLEDGMENTS

We thank Dr. Dave Huggins (USDA-ARS) for providing research space at the USDA Conservation and WSU Cook Farms near Pullman, Washington, and Cunningham Sheep Farms, Newtson Farms, Bracher Farms, and Bill Lorenzen for providing research sites in Oregon. We also thank students Seren Hansen and Stefka Waite, and USDA-ARS agricultural research technicians Bob Correa (Pendleton, Oregon), and Dave Uberuaga (Pullman, Washington) for field work, Joe St. Clair (chemist) for laboratory analyses, Dr. John Sulik (USDA-ARS post-doc, Pendleton, Oregon) for GIS consultation. This research funded by USDA Agricultural Research Service National Program Agricultural Competitiveness and Sustainability (NP#216). USDA is an equal opportunity provider and employer. The mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

[1]U. S. A. Congress, 2007.
[2]USEPA (United State Environmental Protection Agency), 2013.
[3]S. Mufson, in *Washington Post*, Washington D.C., 2013.

[4]R. B. Mitchell, L. L. Wallace, W. W. Wilhelm, G. E. Varvel, and B. J. Wienhold, Grasslands, Rangelands, and Agricultural Systems, p. 9, Ecological Society of America, 2010, www.esa.org/biofuelsreports.
[5]M. E. Walsh, D. G. de la Torre Ugarte, H. Shapouri, and S. P. Slinsky, Environ. Resour. Econ. **24**(4), 313–333 (2003).
[6]J. M. Jungers, J. E. Fargione, C. C. Sheaffer, D. L. Wyse, and C. Lehman, PLoS One **8**(4), e61209 (2013).
[7]J. R. Ehleringer, Oecologia **31**(3), 255–267 (1978).
[8]S. P. Long, Plant Cell Environ. **6**(4), 345–363 (1983).
[9]R. F. Sage, New Phytol. **161**(2), 341–370 (2004).
[10]M. J. Williams and J. Douglas, U.S. Department of Agriculture, Natural Resources Conservation Service, Plant Materials Program, Technical Note No. 4 (Washington D.C., 2011), p. 2.
[11]R. D. Perlack, L. L. Wright, A. F. Turhollow, R. L. Graham, B. J. Stokes, and D. C. Erbach, Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-ton Annual Supply (2005), U.S. Department of Energy and U.S. Department of Agriculture, p. 78, (2005).
[12]H. T. Murphy, D. A. O'Connell, R. J. Raison, A. C. Warden, T. H. Booth, A. Herr, A. L. Braid, D. F. Crawford, J. A. Hayward, T. Jovanovic, J. G. McIvor, M. H. O'Connor, M. L. Poole, D. Prestwidge, N. Raisbeck-Brown, and L. Rye, Renewable Sustainable Energy Rev. **44**, 738–750 (2015).
[13]USDA-NRCS, National Resources Inventory: 2001 Annual NRI (Natural Resource Conservation Service, Washington D.C., 2003), http://www.nrcs.usda.gov/technical/land/nri01/nri01lu.html.
[14]J. B. Kauffman, W. C. Krueger, and M. Vavra, J. Range Manage. **36**(6), 685–691 (1983).
[15]J. D. Williams, D. S. Robertson, and S. B. Wuest, J. Soil and Water Conserv. **70**(3), 156–169 (2015).
[16]W. F. Schillinger and R. I. Papendick, Agron. J. **100**(Supplement 3), S-166–S-182 (2008).
[17]D. Kumar, A. Juneja, W. Hohenschuh, J. D. Williams, and G. S. Murthy, J. Renewable Sustainable Energy **4**(6), 063114 (2012).
[18]R. I. Papendick and W. C. Moldenhauer, U.S. Department of Agriculture, National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161 (1995), p. 64.
[19]D. R. Johnson and A. J. Makinson, Soil Survey of Umatilla County Area, Oregon, USDA—Soil Conservation Service, U.S. Government Printing Office, Washington D.C., 1988.
[20]N. C. Donaldson, Soil Survey of Whitman County, Washington, USDA—Soil Conservation Service, U.S. Government Printing Office, Washington D.C., 1980.
[21]W. F. Schillinger, S. E. Schofstoll, and J. R. Alldredge, Field Crops Res. **109**(1–3), 45–49 (2008).
[22]A. C. Hull, Jr. and R. C. Holmgren, Seeding Southern Idaho Rangeland's, Intermountain Forest and Range Experiment Station, INT-10, U.S. Department of Agriculture, Forest Service, 1965, p. 29.
[23]J. D. Williams, H. M. Hartman, L. M. Spencer, and J. O. Loiland, Am. J. Plant Sci. **2**(6), 744–752 (2011).
[24]J. C. Hoag, S. K. Wyman, G. Bentrup, L. Holzworth, D. G. Ogle, J. Carleton, F. Berg, and B. Leinard, Plant Materials Technical Note No. WY-5, USDA-NRCS, 2001, p. 14.
[25]Y. Zheng, Z. Pan, R. Zhang, J. Labavitch, D. Wang, S. Teter, and B. Jenkins, Appl. Biochem. Biotechnol. **137–140**(1), 423–435 (2007).
[26]E. M. Monono, P. E. Nyren, M. T. Berti, and S. W. Pryor, Ind. Crops Prod. **41**, 331–339 (2013).
[27]R. C. Littell, G. A. Milliken, W. W. Stroup, R. D. Wolfinger, and O. Schabenberger, *SAS for Mixed Models*, 2nd ed. (SAS publishing, SAS Institute Inc., Cary, NC, USA, 2006).
[28]SAS, *SAS/STAT 9.4 User's Guide* (SAS Institute Inc., Cary, NC, USA, 2012).
[29]E. E. Gbur, K. S. McCarter, S. Durham, L. J. Young, M. Christman, M. West, and M. Kramer, *Repeated Measures in Time and Space* (American Society of Agronomy, Soil Science Society of American, and Crop Science Society of America, Madison, Wisconsin, 2012).
[30]H. Weiguo, Y. Zhengwei, D. Liping, and Y. Peng, Trans. Am. Soc. Agric. Biol. Eng. **57**(1), 239–247 (2014).
[31]W. Han, Z. Yang, L. Di, A. L. Yagci, and S. Han, J. Geogr. **113**(3), 129–138 (2014).
[32]W. Han, Z. Yang, L. Di, and R. Mueller, Comput. Electron. Agric. **84**, 111–123 (2012).
[33]C. Boryan, Z. Yang, R. Mueller, and M. Craig, Geocarto Int. **26**(5), 341–358 (2011).
[34]USDA-NASS, U.S. Department of Agriculture, National Agricultural Statistics Service, Washington DC, 2012, http://nassgeodata.gmu.edu/CropScape/ (accessed 02 September 2016).
[35]USEPA, U.S. Environmental Protection Agency Office of Research and Development (ORD)−National Health and Environmental Effects Research Laboratory (NHEERL) Corvallis, Oregon, 2012, ftp://ftp.epa.gov/wed/ecoregions/reg10/reg10_eco_l4.htm (accessed 02 September 2016).
[36]USDI-GS, USDI-Geological Survey, Reston, Virginia, 2013, https://pubs.er.usgs.gov/publication/70046927 (accessed 02 September 2016).
[37]USDI-GS, USDI Geological Survey, Reston, Virginia, 2001, http://viewer.nationalmap.gov/viewer/ (accessed 02 September 2016).
[38]USDA-NRCS, SSURGO Soil Map Coverage versus the U.S. General Soil Map Coverage, United States Department of Agriculture, Natural Resources Conservation Service, 2012, http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053626 (accessed 02 September 2016).
[39]C. Daly, M. Halbleib, J. I. Smith, W. P. Gibson, M. K. Doggett, G. H. Taylor, J. Curtis, and P. P. Pasteris, Int. J. Climatol. **28**(15), 2031–2064 (2008).
[40]D. G. De La Torre Ugarte, M. E. Walsh, H. Shapouri, and S. P. Slinsky, U.S. Department of Agriculture (Office the Chief Economist, Office of Energy Policy and New Uses, Washington DC, 2003), p. 41.
[41]G. W. Mueller-Warrant, G. M. Banowetz, and G. W. Whittaker, Biofuels, Bioprod. Biorefin. **4**(4), 385–407 (2010).
[42]A. A. Boateng, G. M. Banowetz, J. J. Steiner, T. F. Barton, D. G. Taylor, K. B. Hicks, H. El-Nashaar, and V. K. Sethi, Biomass Bioenergy **31**(2–3), 153–161 (2007).
[43]G. M. Banowetz, B. Akwasi, J. J. Steiner, V. K. Sethi, and H. El-Nashaar, Potential for On-farm Thermochemical Conversion of Straw to Bioenergy in the Pacific Northwest, U.S. Department of Agriculuture, Agriculture Research Service, National Forage Seed Production Research Center, Corvallis, Oregon, 2007.
[44]A. Perry, in-house publication of the United States Department of Agriculture, Agricultural Research Service, https://agresearchmag.ars.usda.gov/2011/feb/bioenergy (accessed 02 September 2016). This research supports the USDA

priority of developing new sources of bioenergy and is part of Bioenergy (#213) and Agricultural System Competitiveness and Sustainability (#216), two ARS national programs described at http://www.nps.ars.usda.gov.
[45]G. M. Banowetz, A. Boateng, J. J. Steiner, S. M. Griffith, V. Sethi, and H. El-Nashaar, Biomass Bioenergy **32**(7), 629–634 (2008).
[46]D. R. Huggins, C. E. Kruger, K. M. Painter, and D. P. Uberuaga, Bioenergy Res. **7**(2), 598–608 (2014).
[47]D. Huggins, paper presented at the Proceedings of the 10th International Conference on Precision Agriculture, Denver, Colorado, 2011.
[48]K. R. Woodard and G. M. Prine, Crop Sci. **33**(4), 818–824 (1993).
[49]A. A. Boateng, W. F. Anderson, and J. G. Phillips, Energy Fuels **21**(2), 1183–1187 (2007).
[50]J. H. Cherney, K. D. Johnson, V. L. Lechtenberg, and J. M. Hertel, Biomass **10**(3), 175–186 (1986).
[51]J. C. Clifton-Brown, I. Lewandowski, B. Andersson, G. Basch, D. G. Christian, J. B. Kjeldsen, U. Jørgensen, J. V. Mortensen, A. B. Riche, K.-U. Schwarz, K. Tayebi, and F. Teixeira, Agron. J. **93**(5), 1013–1019 (2001).
[52]A. Hallam, I. C. Anderson, and D. R. Buxton, Biomass Bioenergy **21**(6), 407–424 (2001).
[53]P. R. Adler, M. A. Sanderson, and S. C. Goslee, paper presented at the 4th Eastern Native Grass Symposium, Lexington, Kentucky, 2004.
[54]A. Boe and D. K. Lee, Crop Sci. **47**(3), 929–934 (2007).
[55]S. E. Florine, K. J. Moore, S. L. Fales, T. A. White, and C. Lee Burras, Biomass Bioenergy **30**(6), 522–528 (2006).
[56]D. Tilman, J. Hill, and C. Lehman, Science **314**(5805), 1598–1600 (2006).
[57]M. R. Schmer, K. P. Vogel, R. B. Mitchell, and R. K. Perrin, Proc. Natl. Acad. Sci. **105**(2), 464–469 (2008).
[58]J. F. S. Lamb, C. C. Sheaffer, and D. A. Samac, Agron. J. **95**(3), 635–641 (2003).
[59]T. L. Springer and C. L. Dewald, in *Warm-Season (C4) Grasses*, edited by L. E. Moser, B. L. Burson, and L. E. Sollenberger (American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, 2004), pp. 955–973.
[60]A. Graf and T. Koehler, Oregon Cellulose-ethanol Study: An Evaluation of the Potential for Ethanol Production in Oregon Using Cellulose-based Feedstocks, Oregon Department of Energy, Salem, Oregon and Bryan & Bryan, Inc., 2000, p. 30.
[61]A. Juneja, D. Kumar, J. D. Williams, D. J. Wysocki, and G. S. Murthy, J. Renewable Sustainable Energy **3**(6), 063102 (2011).
[62]M. Sanderson and P. Adler, Int. J. Mol. Sci. **9**(5), 768–788 (2008).
[63]C. J. Smith, Implementation and Effectiveness Monitoring Results for the Washington Conservation Reserve Enhancement Program (CREP): Buffer Performance and Buffer Width Analysis, Washington State Conservation Commission Board Members, Lacey, Washington, 2013, p. 38.
[64]Oregon Conservation Reserve Enhancement Program, 2014 (CREP) Annual Report; see http://www.oregon.gov/OWEB/MONITOR/docs/2014_CREP_Annual_Report.pdf; accessed September 2, 2016.
[65]C. Nickerson, M. Morehart, T. Kuethe, J. Beckman, J. Ifft, and R. Williams, Trends in U.S. Farmland Values and Ownership, EIB-92, U.S. Dept. of Agriculture, Economic Research Service, 2012, p. 48.
[66]D. F. Mir and K. Dick, Nat. Areas J. **32**(2), 190–198 (2012).
[67]A. F. Turhollow, Cost of Producing Biomass from Riparian Buffer Strips, p. 60, United States Department of Energy, Oak Ridge National Laboratory-Energy Division and University of Tennessee-Battelle, LLC for USDOE, Oak Ridge, Tennessee, http://web.ornl.gov/~webworks/cpr/v823/rpt/108548.pdf (accessed 02 September 2016).