Composition and Production of Perennial Grasses for Biofuel Production in Central and Western North Dakota

Paul E. Nyren[2], Qingwu Xue[1], Ezra Aberle[3], Gordon Bradbury[4], Eric Eriksmoen[5], Mark Halvorson[6], Kris Nichols[7], Mark Liebig[7], Rick Bohn[2], Anne Nyren[2], and Bob Patton[2].

[1]North Dakota State Univ. (NDSU), Mandan, ND; [2-6] NDSU Research Extension Centers at [2]Streeter, [3]Carrington, [4]Williston , [5]Hettinger, and [6]Minot, [7] USDA-ARS, Mandan, ND.

The Northern Great Plains has been identified as an important area for biomass production. In particular, North Dakota is ranked first in the nation in potential for producing perennial grasses and other dedicated biofuel crops. With about three million acres of CRP land and over seven million acres of highly erodible land, the state has great potential for liquid biofuel production from biomass crops. Before the great potential for biofuel production can be realized, questions still remain for developing management practices for biofuel crops, such as appropriate species in certain areas, biomass yield potential and quality, and harvesting methods. To answer these questions, a study was initiated in 2006 to evaluate ten cool and warm season grasses and mixtures across central and western North Dakota.

A ten-year field study was initiated in 2006 to evaluate ten entries of perennial grasses and mixtures in two harvest scenarios (annual and biennial). The experimental design was a randomized complete block design with four replications. The plots were seeded at five NDSU Research Extension Centers across central and western North Dakota. Among the five locations, long term growing season precipitation varies from 12.5 inches at Williston to 17 inches at Carrington. However, the variation of mean temperature is small across locations from west to east. At the Williston location, the plots were seeded and managed under both dryland and irrigated conditions. The plots at the other four locations were managed under dryland condition. In total, the grasses/mixtures were grown in six environments.

Biomass Composition

Chemical composition of biomass feedstock is an important factor affecting efficiency of biofuel production and energy outputs. Currently, there are three major technologies for generating energy from biomass: ethanol production from fermentation, direct combustion, and thermochemical conversion by gasification or pyrolysis to produce syngas and liquid fuels. For ethanol production, biomass of ideal composition would contain high concentration of cellulose and hemicellulose, and low concentration of lignin, while for combustion, an ideal biomass would have lower ash content.

The samples for chemical composition analysis were from plots harvested in the fall of 2007. After biomass yield determination, the samples were ground through a 1-mm screen. Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) contents were determined using an ANKOM 200 Fiber

Analyzer (ANKOM Technology Corp., Fairport, NY). Hemicellulose (HCE) and cellulose (CE) contents were determined by subtracting the values of ADF from NDF, and ADL from ADF, respectively. The sample moisture level was measured after oven drying at 216°F for 12 hours. Ash content was determined by combustion of samples in a muffle furnace at 930°F for 12 hours.

Qingwu Xue (left) and Paul Nyren harvesting biomass plots at CGREC in 2009.

Among the five locations in six environments, samples from the Hettinger and Williston dryland sites had higher NDF and ADF than those in other environments, and those in Minot had the lowest (Table 1). However, there was no clear trend in ADL, HCE, CE and ash content among environments, indicating that factors other than precipitation affect biomass chemical composition. In general, samples from Williston and Streeter had higher ADL. Samples from Minot and Streeter had lower HCE but higher ash content than other environments. At the Williston location, direct comparisons of biomass composition can be made between the dryland and irrigated plots. Averaged over species and mixtures, samples under dryland had higher NDF, ADL and HCE but lower CE than those under irrigated conditions (Table 1).

Overall, tall wheatgrass and its mixtures had superior quality to other species for ethanol production as a result of high cellulose and low ADL. For direct combustion, tall wheatgrass also seemed better than other species because of low ash content.

Table 1. Effect of environment on biomass chemical composition of perennial grasses harvested in 2007.

Locations	NDF	ADF	ADL	HCE	CE	Ash
	----------	----------	g/kg	----------	----------	----------
Hettinger	802.4	526.0	116.5	276.4	409.5	65.2
Williston-dryland	802.3	510.7	176.4	291.7	334.2	52.8
Williston-irrigated	776.1	517.7	142.7	258.3	375.0	62.7
Streeter	693.4	480.4	134.0	212.8	346.3	99.1
Minot	679.2	454.0	105.6	225.2	348.4	82.8
Carrington	770.3	483.3	119.5	287.0	363.8	65.9
Mean	**753.9**	**495.3**	**132.5**	**258.6**	**362.9**	**71.4**
LSD (0.05)	**18.4**	**14.6**	**9.8**	**13.2**	**14.8**	**5.6**

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin; HCE: Hemicellulose (NDF-ADF); CE: Cellulose (ADF-ADL).

Annual Production

The biomass plots were harvested the 3rd week of September. We again used the self-propelled harvester from the USDA-ARS, Mandan. The harvest started in **Hettinger** with the plots that were reseeded in 2008. The highest yielding plots were the CRP mix with alfalfa and sweetclover with an average of 1.68 tons/acre (Table 2). The plots that contained Trailblazer and Sunburst switchgrass consisted mostly of grasses other than switchgrass. None of the yields at the Hettinger site were significantly different at the 0.05 level.

Yields at **Minot** were down from the two previous years. Sunburst switchgrass/tall wheatgrass had the best production with 3.25 tons/acre down from 4.09 tons/acre in 2008 and 4.58 tons/acre in 2007. None of the yields at Minot in 2009 were significantly different at the 0.05 level. Sunburst switchgrass/tall wheatgrass has the highest three-year average yield with 3.97 tons/acre. While the switchgrass portion of these plots looked better in 2009 over 50 percent of the production in these plots was due to the tall wheatgrass component (Table 2).

For the second year in a row Sunburst switchgrass was the highest producer in the **Carrington** plots with a yield of 4.91 tons/acre which was significantly higher than all other entries except switchgrass/Altai wildrye plots with 4.43 tons/acre. All the plots at Carrington yielded over 3 tons/acre and were the best yielding dryland plots

Harvesting biofuel plots at CGREC, Streeter. Paper bags contain sub-samples used for moisture determination and quality analysis.

in the study. The best three-year average yield in the study at Carrington was the Sunburst switchgrass plots with 5.14 tons/acre (Table 2).

Intermediate wheatgrass was the highest yielding species at the **Streeter** site in 2009 with a total yield of 3.31 tons/acre. At this site the switchgrass mixtures

were nearly 100 percent species other than switchgrass. The plots with only switchgrass were reseeded in 2008 and germination was better that in 2006 but there is still an abundance of quackgrass and bromegrass in these plots. In the three-year averages at Streeter, Sunburst/tall wheatgrass plots had the highest yields, but again these plots mostly consisted of tall wheatgrass. This was followed closely by Alkar tall wheatgrass alone, the CRP grass mix and Haymaker intermediate wheatgrass, all of which were not significantly different (Table 2).

The dryland plots at **Williston** were harvested for the third year in 2009. They produced even less than the plots at Hettinger with a top yield of 1.27 tons/acre for intermediate wheatgrass followed closely by the CRP grass mix, and Alkar tall wheatgrass alone, at 1.05 tons/acre. Intermediate wheatgrass has been the top yielding species each of the three years of the study with a three-year average of 1.09 tons/acre (Table 3).

Again in 2009 the irrigated plots at **Williston** had the highest yields with Sunburst switchgrass yielding 5.76 tons/acre. This was followed closely by Sunburst switchgrass/Altai wildrye mix at 5.72 tons/acre and Sunburst switchgrass/big bluestem mix with 5.02 tons/acre, none of which were statistically different from each other. Sunburst switchgrass alone also had the highest three-year average with 6.29 tons/acre followed closely by Sunburst switchgrass/Altai wildrye mix at 5.75 tons/acre (Table 3).

Biennial Production

The biomass study has two sets of plots planted with each species and species mix. One set of plots is harvested annually while the other set is harvested every other year (biennial harvest). The biennial plots were not harvested in 2008 so the harvest in 2009 contained the remaining production from 2008 as well as that of 2009. Since the plots at Hettinger were seeded in 2008 there was no biennial harvest data from these plots. At all locations except Hettinger the biennial plots were harvested the first year (2007) and again in 2009. These data were compared

with the three harvests of the annual plots. The two harvests of the biennial plots were added together and then divided by three to make the yields comparable with the three-year annual harvest. Table 2 and Table 3 shows the production data for the biennial plots.

With the exception of the Sunburst switchgrass plots at Minot all biennial plots yielded less over the three years than did the annual plots. The lower yields of the biennial harvest varied considerably by location. The Carrington biennial plots yielded 30.3 percent less than did the annual harvest with all the plots showing significantly less production while the plots at Minot saw a 15.4 percent lower yield. The other sites had 19-20 percent less production on the biennial plots versus the annually harvested plots. The variability in the amount of yield on the biennial plots is hard to explain. Both Basin and Altai wildrye are known to stand erect during the winter and the sites at Minot and Williston irrigated did have higher production than other sites where the plots contained a poor stand of the wildryes. The question that bears further investigation is what is the economic advantage of a biennial harvest over an annual one? There would be the obvious harvest cost savings but would this offset the loss in total yield? In a large field situation the standing crop in the year with no harvest might trap enough snow to aid in the production the following year. There certainly would be an advantage to upland nesting game birds and there might be some economic returns from hunting, etc. The harvest method might have some impact on these numbers. We used a machine which harvested the standing crop like a swather. If we had used a mower and rake we might have captured more of the litter from the ground increasing the yield of the biennial plots. This study will continue through 2016.

Table 2. Forage production (tons/ac) on non-irrigated annual and biennial harvest systems of selected species at each location, 2007-2009. Bolded numbers in each column show the top producing species at each location each year.

Location and Species	Annual Harvest 2007		Annual Harvest 2008		Annual Harvest 2009		Biennial Harvest 2007		Biennial Harvest 2009		Annual 3-Year-Avg 2007-09		Biennial 3-Year-Avg 2007-09			Percent Difference
Carrington																
Alkar Tall Wheatgrass	4.66	bcde[1]	4.37	abc	3.95	bcd	4.77		4.04	bc	4.33	bcd	2.94	abc	*[2]	32.1
CRP Mix (Intermediate & Tall Wheatgrass)	4.16	de	3.75	bcd	3.42	de	4.35		3.47	c	3.78	def	2.61	bc	*	31.0
CRP Mix (Wheatgrasses +Alfalfa+Sweetclover)	4.93	cde	3.79	cd	3.23	e	4.36		3.18	c	3.98	cde	2.51	bc	*	36.9
Haymaker Intermediate Wheatgrass	4.45	bcd	3.35	bcd	3.22	e	4.52		3.42	c	3.67	ef	2.65	bc	*	27.9
Magnar Basin + Mustang Altai Wildrye	3.86	e	3.12	d	3.11	e	4.13		3.08	c	3.36	f	2.40	c	*	28.6
Sunburst Switchgrass	5.36	abc	**5.13**	a	**4.91**	a	5.46		5.36	ab	**5.14**	a	**3.61**	a	*	29.8
Sunburst Switchgrass + Mustang Altai Wildrye	5.18	bc	4.96	ab	4.43	ab	5.03		**5.76**	a	4.86	ab	3.60	a	*	26.0
Sunburst Switchgrass + Sunnyview Big Bluestem	5.48	ab	4.86	ab	4.21	bc	5.25		5.24	ab	4.85	ab	3.50	a	*	27.9
Sunburst Switchgrass + Tall Wheatgrass	5.29	abc	4.00	abcd	3.99	bcd	4.99		4.11	bc	4.43	bc	3.03	abc	*	31.5
Trailblazer Switchgrass	**6.21**	a	4.57	abc	3.69	cde	**5.92**		4.02	bc	4.82	ab	3.31	ab	*	31.3
LSD 0.05	1.01		1.25		0.67		NS		1.59		0.60		0.82			
R^2	0.65		0.55		0.75				0.59		0.79		0.56			
Hettinger[3]																
Alkar Tall Wheatgrass	-		-		1.10		-		1.43							
CRP Mix (Intermediate & Tall Wheatgrass)	-		-		1.34		-		1.22							
CRP Mix (Wheatgrasses +Alfalfa+Sweetclover)	-		-		**1.68**		-		1.59							
Haymaker Intermediate Wheatgrass	-		-		1.64		-		**1.75**							
Magnar Basin + Mustang Altai Wildrye	-		-		1.30		-		1.35							
Sunburst Switchgrass	-		-		1.51		-		1.27							
Sunburst Switchgrass + Mustang Altai Wildrye	-		-		1.60		-		1.29							
Sunburst Switchgrass + Sunnyview Big Bluestem	-		-		1.43		-		1.41							
Sunburst Switchgrass + Tall Wheatgrass	-		-		1.52		-		1.30							
Trailblazer Switchgrass	-		-		1.06		-		1.42							
LSD 0.05					NS				NS							
R^2																
Minot																
Alkar Tall Wheatgrass	4.19	a	4.10	a	3.13		**4.79**	a	**5.42**		3.81	ab	**3.41**	a		10.5
CRP Mix (Intermediate & Tall Wheatgrass)	4.47	a	3.58	ab	2.04		3.98	ab	4.08		3.36	abc	2.69	abc	*	20.1
CRP Mix (Wheatgrasses +Alfalfa+Sweetclover)	4.12	a	3.23	ab	2.80		3.39	bc	4.19		3.38	abc	2.52	bcd	*	25.4
Dakota Switchgrass	1.54	b	1.32	c	2.36		1.15	e	3.21		1.74	e	1.45	e		16.4
Haymaker Intermediate Wheatgrass	3.67	a	**4.13**	a	2.45		2.93	bcd	3.76		3.42	abc	2.23	cd	*	34.7
Magnar Basin + Mustang Altai Wildrye	2.35	b	2.47	bc	2.72		2.83	bcd	4.20		2.51	cde	2.35	bcd		6.6
Sunburst Switchgrass	2.39	b	1.63	c	2.23		2.25	cde	4.33		2.08	de	2.19	cde		-5.2
Sunburst Switchgrass + Mustang Altai Wildrye	2.29	b	3.57	ab	3.09		2.94	bcd	4.38		2.98	bcd	2.44	bcd		18.2
Sunburst Switchgrass + Sunnyview Big Bluestem	2.14	b	1.68	c	2.03		2.07	de	3.59		1.95	e	1.89	de		3.3
Sunburst Switchgrass + Tall Wheatgrass	**4.58**	a	4.09	a	**3.25**		3.73	ab	5.33		**3.97**	a	3.02	ab		24.0
LSD 0.05	1.17		1.35		NS		1.27		NS		0.98		0.75			
R^2	0.79		0.73				0.72				0.72		0.68			
Streeter																
Alkar Tall Wheatgrass	3.42	a	2.63	ab	2.32		3.27	ab	4.02	ab	2.79	a	2.43	ab		12.9
CRP Mix (Intermediate & Tall Wheatgrass)	3.38	a	2.67	ab	2.69		3.35	ab	3.55	bc	2.91	a	2.30	b		20.9
CRP Mix (Wheatgrasses +Alfalfa+Sweetclover)	2.56	b	1.65	cd	2.06		2.62	cd	2.99	bcd	2.09	b	1.87	c		10.6
Haymaker Intermediate Wheatgrass	2.70	b	2.74	ab	**3.31**		2.78	bc	2.86	cd	2.92	a	1.88	c	*	35.5
Magnar Basin + Mustang Altai Wildrye	1.67	c	1.51	cd	1.83		1.36	f	2.51	ed	1.67	bc	1.29	d		22.7
Sunburst Switchgrass	1.88	c	0.74	de	1.98		1.80	ef	1.63	ef	1.53	bc	1.14	d		25.4
Sunburst Switchgrass + Mustang Altai Wildrye	1.79	c	2.10	bc	2.37		1.51	ef	2.78	cd	2.09	b	1.43	d		31.6
Sunburst Switchgrass + Sunnyview Big Bluestem	1.59	c	1.98	bc	1.86		1.56	ef	2.77	cd	1.81	bc	1.44	d		20.2
Sunburst Switchgrass + Tall Wheatgrass	**3.94**	a	**3.09**	a	2.53		**3.41**	a	**4.75**	a	**3.19**	a	**2.72**	a		14.8
Trailblazer Switchgrass	1.71	c	0.00	e	1.83		2.03	de	1.24	f	1.18	c	1.09	d		8.0
LSD 0.05	0.67		0.96		NS		0.62		1.04		0.64		0.41			
R^2	0.87		0.80				0.87		0.80		0.82		0.88			

[1] Numbers in the same column followed by the same letter are not significantly different ($p \leq 0.05$).

[2] * denotes a significant difference in production between annual and biennial harvests. [3] The Hettinger site was replanted in 2008.

Table 3. Forage production (tons/ac) on dryland irrigated annual and biennial harvest systems of selected species at Williston Research Extension Center 2007-2009. Bolded numbers in each column show the top producing species at each location each year.

Location and Species	Annual Harvest			Biennial Harvest		Annual 3-Year-Avg	Biennial 3-Year-Avg	Percent
	2007	2008	2009	2007	2009	2007-09	2007-09	Difference
Williston -dryland								
Alkar Tall Wheatgrass	0.96 ab[1]	0.70	1.05 ab	1.03 a	1.16	0.91 ab	0.73 abc	19.6
CRP Mix (Intermediate & Tall Wheatgrass)	1.04 a	0.72	1.05 ab	**1.10** a	**1.40**	0.94 ab	**0.83** a *[2]	11.4
CRP Mix (Wheatgrasses +Alfalfa+Sweetclover)	0.87 abc	0.62	0.78 c	0.83 ab	0.95	0.75 bc	0.59 abcd *	21.6
Dakota Switchgrass	0.35 bc	0.60	0.84 bc	0.33 bc	1.16	0.60 c	0.50 cd	17.1
Haymaker Intermediate Wheatgrass	**1.23** a	**0.79**	**1.27** a	**1.10** a	1.22	**1.09** a	0.78 ab *	29.2
Magnar Basin + Mustang Altai Wildrye	0.27 c	0.61	0.90 bc	0.28 bc	1.22	0.59 c	0.50 cd	15.9
Sunburst Switchgrass	0.27 c	0.50	0.93 bc	0.00 c	1.35	0.57 c	0.45 d	20.2
Sunburst Switchgrass + Mustang Altai Wildrye	0.31 bc	0.75	0.85 bc	0.38 bc	1.31	0.64 c	0.56 bcd	11.7
Sunburst Switchgrass + Sunnyview Big Bluestem	0.35 bc	0.69	1.00 bc	0.31 bc	1.15	0.68 c	0.49 cd	28.4
Sunburst Switchgrass + Tall Wheatgrass	1.06 a	0.68	0.93 bc	0.89 ab	1.24	0.89 ab	0.71 abcd *	20.2
LSD 0.05	0.67	NS	0.26	0.63	NS	0.21	0.26	
R^2	0.57		0.54	0.62		0.75	0.52	
Williston-irrigated								
Alkar Tall Wheatgrass	4.98 ab	3.16 e	3.84 bcd	5.06 bc	5.48 c	3.99 de	3.51 bc	12.1
CRP Mix (Intermediate & Tall Wheatgrass)	4.50 bc	3.24 e	2.80 d	4.55 bc	4.18 d	3.51 ef	2.91 cd *	17.2
CRP Mix (Wheatgrasses +Alfalfa+Sweetclover)	3.72 c	2.80 e	3.48 cd	4.16 bc	3.82 d	3.33 f	2.66 d *	20.1
Dakota Switchgrass	4.31 bc	4.91 c	4.75 ab	4.33 bc	5.43 c	4.66 c	3.26 cd *	30.1
Haymaker Intermediate Wheatgrass	4.20 bc	3.35 e	3.72 bcd	4.02 bc	3.93 d	3.76 ef	2.65 d *	29.4
Magnar Basin + Mustang Altai Wildrye	4.19 bc	3.06 e	3.31 cd	3.82 c	6.57 bc	3.52 ef	3.46 bc	1.6
Sunburst Switchgrass	5.83 a	**7.28** a	**5.76** a	5.68 ab	6.96 b	**6.29** a	4.21 a *	33.0
Sunburst Switchgrass + Mustang Altai Wildrye	**5.85** a	5.69 b	5.72 a	**6.92** a	7.09 ab	5.75 ab	**4.67** a	18.8
Sunburst Switchgrass + Sunnyview Big Bluestem	4.92 ab	5.87 b	5.02 a	5.01 bc	**8.23** a	5.27 b	4.41 a *	16.3
Sunburst Switchgrass + Tall Wheatgrass	5.61 a	4.27 d	3.92 bc	5.85 ab	6.12 bc	4.60 cd	3.99 ab	13.2
LSD 0.05	1.03	0.59	1.04	1.84	1.62	0.61	0.70	
R^2	0.68	0.96	0.79	0.52	0.86	0.91	0.81	

[1] Numbers in the same column followed by the same letter are not significantly different ($p \leq 0.05$).

[2] * denotes a significant difference in production between annual and biennial harvests.

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