Biomass Yield of Perennial Forage Species for Bioenergy in North Dakota

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North Dakota has great potential to produce perennial herbaceous biomass for bioenergy purposes. Information about the performance of switchgrass cultivars and other promising perennial species in five regions of North Dakota is presented. This information could be used to diversify biomass production systems to fit site-specific situations.

Summary
Objectives of this study were to compare establishment, stand persistence and yield of five perennial forage species and six mixtures across central and western North Dakota. The establishment of warm-season grasses (switchgrass and big bluestem) in western North Dakota was problematic regardless of cultivar selection, likely due to limited precipitation during the growing season. However, in central North Dakota, or western North Dakota with irrigation, their establishment was successful. On the research sites with well-established stands of switchgrass, 'Sunburst' produced more than 'Dakotah' or 'Trailblazer.' Stands of warm-season grasses decreased during the six years due to invasion of cool-season grasses. In areas where warm-season grasses did not establish well, intermediate wheatgrass had the highest yield ($P < 0.05$). Mixtures were at least comparable to, and sometimes higher than, their compositional component monocultures. At Carrington, 'Sunburst' switchgrass alone (4.6 tons/acre) or mixed with Altai wildrye (4.4 tons/acre) or big bluestem (4.5 tons/acre) had the highest production ($P < 0.05$). At Minot, tall wheatgrass alone (3.1 tons/acre) or mixed with 'Sunburst' switchgrass (3.4 tons/acre) and intermediate wheatgrass, alfalfa and sweetclover (3.2 tons/acre) produced more ($P < 0.05$). At Streeter, 'Sunburst' switch-grass alone (2.7 tons/acre) and mixed with tall wheatgrass (2.7 tons/acre) produced more ($P < 0.05$). Intermediate wheatgrass was superior ($P < 0.05$) at Hettinger (2.2 tons/acre) and the Williston (1.3 tons/acre) dryland site. In comparison, 'Sunburst' switchgrass alone (5.9 tons/acre) or mixed with Altai wildrye (5.6 tons/acre) yielded best ($P <$ 0.05) at the Williston irrigated site.

Introduction
The northern Great Plains has been identified as an important area for biomass production. In particular, North Dakota is ranked first in the nation for its potential to produce perennial grasses and other dedicated bioenergy crops (Milbrandt, 2005). With more than 7 million

acres of highly erodible and saline cropland, as well as 3 million acres of Conservation Reserve Program land (USDA-Farm Service Agency, 2013), some counties in the western part of the state have as much as 90 percent of the cropland classified for bioenergy crop production (USDA-Farm Service Agency, 2012). However, historical studies on switchgrass biomass production, except Berdahl et al. (2005), were mainly in eastern North Dakota, and the establishment and yield of switchgrass in western North Dakota still remains mostly unknown.

Furthermore, switchgrass cultivars of southern origins such as ‘Alamo,’ ‘Kanlow,’ ‘Cave-in-Rock’ and ‘Blackwell’ had uncertain winter hardiness 500 kilometers north of their origin. Evaluation and selection of adapted cultivars of switchgrass is important even if switchgrass can establish in western North Dakota.

Therefore, the objectives of this study were to compare cultivars of switchgrass, intermediate wheatgrass and tall wheatgrass in monocultures, as well as mixtures of 1) intermediate wheatgrass and tall wheatgrass, 2) intermediate wheatgrass, tall wheatgrass, alfalfa and yellow sweetclover, 3) switchgrass and tall wheatgrass, 4) switchgrass and Altai wildrye, 5) switchgrass and big bluestem and 6) Altai wildrye and basin wildrye with regard to establishment, stand persistence, and yield across central and western North Dakota.

Several questions were asked: 1) Could switchgrass be established and persist in central and western North Dakota west of 98° W longitude? 2) If so, which cultivar would be most productive? 3) If not, what is the alternative to switchgrass? 4) Are monocultures and mixtures similar in production or which is superior? 5) What is the best species or mixtures in each site for biomass production?

Procedures

Field study was conducted at the North Dakota State University Research Extension Centers at Carrington (east-central North Dakota), Hettinger (southwestern North Dakota), Minot (north-central North Dakota), Streeter (south-central North Dakota) and Williston (northwestern North Dakota) from 2006 to 2012. The growing season 30-year average precipitation trend is Carrington (15.2 inches), which is greater than at all of the others: Streeter (13.7 inches), Minot (13.1 inches), Hettinger (12.1 inches) and Williston (11.6 inches). At Williston, a side-by-side site comparison of irrigation effect was conducted, and included dryland and irrigated sites. Irrigated plots received approximately 6 to 10 inches of water every year as necessary.

The 10 experimental entries of monocultures and mixtures are shown in Table 1. Each field plot measures 30 feet long and 15 feet wide and contains 30 rows spaced 6 inches apart. In 2006, all plots across all sites were seeded the week of May 15, starting in Hettinger and ending with Carrington, following seedbed preparation with disking and harrowing. The seeding rate for each experimental entry is shown in Table 1.

The field plots at each site were maintained by different mowing agendas, and herbicides were used for weed control if necessary. The plots were not harvested in 2006 but were mowed at the end of the growing season. Since 2007, plots of each experimental entry were harvested every year in the second or third week of September, depending on the weather.

A 4-foot-wide strip in the center of each plot was cut to a 3-inch stubble height and weighed. The dry-matter content of the biomass from each plot was measured from a 1- to 2-pound grab sample that was dried at 150 F and used to adjust plot yields to a dry-matter basis. Plot species composition (weeds and seeded species) were monitored visually during the harvest process. Beginning in 2007, nitrogen fertilizer (50 pounds N/acre) was applied to all plots except those containing legumes.

Results and Discussion

Establishment and persistence. Table 2 shows that the establishment of cool-season grasses (intermediate wheatgrass and tall wheatgrass) was successful for all study sites; however, the establishment of warm-season grasses (switchgrass and big bluestem) was problematic at the Hettinger and Williston dryland sites. Through the years, all sites were invaded by cool-season grasses (smooth brome, and/or quackgrass and/or crested wheatgrass).

Several factors could contribute to stand failure in establishing perennial grasses: for example, moisture stress (Sanderson et al., 1999), seeding strategies (McGinnies, 1960) and seed quality (Panciera and Jung, 1984), as well as weed control (Martin et al., 1982; Mitchell et al., 2010). Stand failure of the warm-season grasses at the Williston dryland site as compared with the establishment success at the irrigation site, which derived from the same seed batch, seeding strategy, weed control and soil characteristics, suggest that the establishment of the warm-season grasses at the Williston site was mainly driven and constrained by available soil water in the seeding year.

Stand failure in 2007 of the warm-season grasses seeded at the Hettinger site in 2006 (a warmer and drier than average year), followed by another stand failure in 2009 (reseeded in 2008, a wetter and colder year), indicates two possible explanations. First, tall-statured warm-season grasses simply cannot be established in the Hettinger area unless extra moisture is available due to topography or irrigation. Second, rather than moisture or temperature controlling these grasses' establishment, a different seeding strategy or weed control may play a key role in this area. Further aspects of seedbed preparation, seeding date, seeding depth and seeding rate should be considered if the establishment of warm-season grasses at Hettinger is the goal.

Furthermore, landscape-level soil variability may contribute to the stand failure due to soil texture and soil salinity. Fortunately, this study indicates that intermediate wheatgrass may serve as an alternative biomass crop in these dry areas from the establishment perspective.

At Streeter and Minot, weed control was crucial in the establishment of the warm-season grasses. However, during the course of the six-year study period, warm-season grasses composition increased, which may indicate the need to allow more time for these grasses to achieve optimum site occupancy. For weed control in switchgrass and big bluestem stands, atrazine can be used pre-emergence (Hintz et al., 1998), or glyphosate can be applied before spring growth of these warm-season grasses.

Yield. Averaged across all the experimental entries and years, the irrigated site at Williston had the highest ($P < 0.05$) yield (4.2 tons/acre), followed by Carrington (4.1 tons/acre), then Minot (2.9 tons/acre), Streeter (2.4 tons/acre) and Hettinger (1.9 tons/acre). The lowest yield occurred at the Williston dryland site (1.1 tons/acre).

Wide variability in biomass yield of switchgrass has been reported in other studies: 1.4 to 5.6 tons/acre in Mandan and Dickinson, N.D. (Berdahl et al., 2005); 4.4 to 5.8 tons/acre in northeastern South Dakota (Boe and Lee, 2007); 0.9 to 4.0 tons/acre in central South Dakota (Lee and Boe, 2005); 3.0 to 5.8 tons/acre in southern Iowa (Lemus et al., 2002); and 3.6 to 8.9 tons/acre in Texas (Sanderson et al., 1999).

Table 3 shows that in our study, 'Sunburst' switchgrass consistently produced the highest from 2007 to 2012 at the Williston irrigated site and Carrington, with an average yield of 5.9 and 4.6 tons/acre, respectively. At the Williston dryland site and at Hettinger, intermediate wheatgrass was consistently the highest producer from 2007 to 2012, with an average yield of 1.3 and 2.2 tons/acre, respectively. At Minot, tall wheatgrass and its mixtures had the highest yield in 2007, 2008 and 2012, while from 2009 to 2011, all the entries were similar. As a result, the six-year average was highest for tall wheatgrass and its mixtures (3.1 tons/acre).

From 2007 to 2008, the Streeter site showed a similar trend as the Minot site, with cool-season grasses producing more than warm-season grasses. Yields were similar in 2009 and 2010, while in 2011 and 2012, 'Sunburst' switchgrass produced the highest (4.3 tons/acre in 2011). The six-year average yield of 'Sunburst' switchgrass alone and mixed with tall wheatgrass (2.7 tons/acre) was the highest. Mixtures are at least comparable with and sometimes higher than their compositional component monocultures.

The cultivars of switchgrass we studied are all of the upland type, but from different origins. Normally, southern origin, later-maturing cultivars would produce more than northern origin, early maturing cultivars (Casler et al., 2004). However, more southern origin cultivars may suffer from winter kill (Berdahl et al., 2005). The North Dakota origin cultivar 'Dakotah' did not show superior stand establishment or production when compared with South Dakota origin cultivar 'Sunburst.' Southern origin cultivar 'Trailblazer' did show some stand decrease through the years at Streeter and Carrington. Its production was higher than 'Sunburst' only in 2007 at Carrington.

Based on our experimental design, running statistical analysis on diversity effects on stand establishment and yield is not appropriate; however, we can compare the mixture stand and yield to its compositional components one by one. Diverse species of monocultures and their mixtures will increase landscape level diversity, increase plant community resistance to invasion and disease outbreak, and improve wildlife habitat diversity.

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Table 1. Experimental entries of species monoculture or mixture and the corresponding seeding rate for evaluating biomass yield for bioenergy across central and western North Dakota in May 2006.

Species or Mixtures	Abbreviation	Species Traits[1]	Seeding Rate[2]
'Sunburst' switchgrass	Sunburst	C_4 Grass	10
'Trailblazer' switchgrass[3]	Trailblazer	C_4 Grass	10
'Dakotah' switchgrass[3]	Dakotah	C_4 Grass	10
'Alkar' tall wheatgrass	Alkar	C_3 Grass	11
'Haymaker' intermediate wheatgrass	Haymaker	C_3 Grass	10
CRP[4] mix 1	CRP1		
'Haymaker' intermediate wheatgrass		C_3 Grass	5
'Alkar' tall wheatgrass		C_3 Grass	6
CRP mix 2	CRP2		
'Haymaker' intermediate wheatgrass		C_3 Grass	4
'Alkar' tall wheatgrass		C_3 Grass	4.5
'Vernal' alfalfa		Legume	1
'Blossom' yellow sweetclover		Legume	0.5
$C_4 + C_3$[1] 1	$C_4C_3$1		
'Sunburst' switchgrass		C_4 Grass	5
'Alkar' tall wheatgrass		C_3 Grass	5
$C_4 + C_3$ 2	$C_4C_3$2		
'Sunburst' switchgrass		C_4 Grass	7
'Mustang' Altai wildrye		C_3 Grass	11
C_4 combination	C_4C_4		
'Sunburst' switchgrass		C_4 Grass	7
'Sunnyview' big bluestem		C_4 Grass	2.5
C_3 combination	C_3C_3		
'Mustang' Altai wildrye		C_3 Grass	11
'Magnar' basin wildrye		C_3 Grass	5

[1] C_4: warm-season species; C_3: cool-season species.
[2] pounds pure live seed/acre.
[3] 'Trailblazer' switchgrass was seeded at Hettinger, Streeter and Carrington, while 'Dakotah' switchgrass was planted at Williston and Minot.
[4] CRP: Conservation Reserve Program.

Table 2. Stand establishment and persistence at harvest of 10 experiment entries for evaluating biomass yield for bioenergy across central and western North Dakota 2007-2012.

	Stand Establishment and Persistence (%)					
Entry[1]	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
			Carrington			
Sunburst	100a[2]	100a	100	95	70	50
Trailblazer	100a	99ab	100	68	70	57
Alkar	100a	100a	100	100	100	100
Haymaker	100a	99ab	100	100	100	100
CRP1	99a	97ab	100	100	100	100
CRP2	87b	82c	100	100	100	100
C_4C_31	100a	100a	100	100	100	100
C_4C_32	100a	100a	100	72	100	67
C_4C_4	100a	97ab	100	73	100	63
C_3C_3	96a	88bc	100	90	98	90
			Hettinger			
Sunburst	2c	--[3]	0c	0d	--[4]	--
Trailblazer	3c	--	7c	0d	--	--
Alkar	80a	--	63ab	92a	--	--
Haymaker	86a	--	100a	82ab	--	--
CRP1	87a	--	100a	70abc	--	--
CRP2	78a	--	100a	67bc	--	--
C_4C_31	70ab	--	83a	50c	--	--
C_4C_32	9c	--	23bc	0d	--	--
C_4C_4	4c	--	0c	0d	--	--
C_3C_3	8c	--	40bc	2d	--	--
			Minot			
Sunburst	35c	99a	100	100	100	77bc
Dakotah	18c	83b	83	73	60	43d
Alkar	100a	100a	100	100	98	73c
Haymaker	100a	100a	100	100	100	100a
CRP1	100a	100a	100	100	100	100a
CRP2	100a	100a	100	100	100	97ab
C_4C_31	100a	100a	100	100	100	83abc
C_4C_32	67b	95a	100	100	97	73c
C_4C_4	40bc	95a	100	100	100	83abc
C_3C_3	20c	93a	100	98	100	63cd
			Streeter			
Sunburst	33b	33b	72a	93a	100a	100a
Trailblazer	2c	0b	0b	40bc	80ab	75ab
Alkar	100a	100a	100a	100a	67b	33bc
Haymaker	100a	100a	100a	100a	83ab	100a
CRP1	100a	100a	100a	97a	100a	100a
CRP2	100a	100a	100a	100a	100a	83a
C_4C_31	98a	100a	100a	100a	100a	75ab
C_4C_32	10bc	32b	73a	80a	100a	60ab
C_4C_4	15bc	37b	73a	67ab	97a	100a
C_3C_3	3c	8b	0b	18c	0c	0c

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Table 2 continued

			Williston Dryland			
Sunburst	32b	3c	20b	33b	53b	63b
Dakotah	28b	7bc	20b	13bc	25bc	40b
Alkar	100a	22b	100a	17bc	58ab	7c
Haymaker	100a	88a	100a	93a	98a	97a
CRP1	98a	87a	100a	100a	98a	100a
CRP2	100a	99a	100a	100a	100a	100a
$C_4C_3$1	87a	8bc	100a	5c	33bc	40b
$C_4C_3$2	15b	2c	20b	20bc	33bc	47b
C_4C_4	13b	0c	20b	38b	35bc	57b
C_3C_3	17b	2c	20b	0c	0c	0c
			Williston Irrigated Land			
Sunburst	100	100	100	100a	100	100a
Dakotah	100	100	100	100a	100	100a
Alkar	100	100	100	100a	100	67b
Haymaker	100	100	100	100a	100	97a
CRP1	100	100	100	100a	100	90ab
CRP2	100	100	100	100a	100	93ab
$C_4C_3$1	100	100	100	100a	100	100a
$C_4C_3$2	100	100	100	100a	100	66b
C_4C_4	100	100	100	100a	100	100a
C_3C_3	100	100	100	50b	100	27c

[1] Experimental entry lists and abbreviations are shown in Table 1.
[2] Within columns for each site, means followed by the same letter are not significantly different at the *P* = 0.05 level.
[3] Data not available for 2008 due to reseeding.
[4] No harvest in 2011 or 2012 due to poor stand establishment.

Table 3. Yield at harvest of 10 experiment entries for evaluating biomass yield for bioenergy across central and western North Dakota 2007-2012.

	Yield (ton/acre)						
Entry[1]	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**Average**
			Carrington				
Sunburst	5.4abc[2]	5.1a	4.9a	4.1ab	4.2	4.0	4.6a
Trailblazer	6.2a	4.6abc	3.7cde	3.3cde	4.3	3.5	4.3ab
Alkar	4.7bcde	4.4abc	4.0bcd	4.2a	4.6	4.2	4.3ab
Haymaker	4.5cde	3.3cd	3.2e	3.0de	3.5	3.3	3.5cd
CRP1	4.2de	3.8bcd	3.4de	3.2de	4.7	3.7	3.8bc
CRP2	5.0bcd	3.8bcd	3.3e	3.3de	4.3	3.5	3.8bc
$C_4C_3$1	5.3abc	4.0abcd	4.0bcd	3.5bcd	4.2	4.0	4.2ab
$C_4C_3$2	5.2bc	5.0ab	4.4ab	3.4bcd	4.2	3.9	4.4a
C_4C_4	5.5ab	4.9ab	4.2bc	4.0abc	4.3	4.2	4.5a
C_3C_3	3.9e	3.1d	3.1e	2.8e	3.6	3.0	3.3d
			Hettinger				
Sunburst	1.7d	--[3]	1.5	2.1	--[4]	--	1.7
Trailblazer	1.7d	--	1.1	2.5	--	--	1.7
Alkar	2.3abcd	--	1.1	2.1	--	--	1.8
Haymaker	2.7ab	--	1.7	2.4	--	--	2.2
CRP1	2.6ab	--	1.3	2.2	--	--	2.1
CRP2	2.9a	--	1.7	2.3	--	--	2.3
$C_4C_3$1	2.5abc	--	1.5	2.2	--	--	2.1
$C_4C_3$2	1.8cd	--	1.6	2.2	--	--	1.9
C_4C_4	1.7d	--	1.4	2.1	--	--	1.7
C_3C_3	1.9bcd	--	1.3	1.6	--	--	1.6
			Minot				
Sunburst	2.4b	1.7c	2.2	3.5	3.1	1.9bc	2.5d
Dakotah	2.3b	1.3c	2.4	4.0	3.5	2.0bc	2.5cd
Alkar	4.2a	4.1a	3.1	3.3	2.6	1.4c	3.1abc
Haymaker	3.7a	4.2a	2.5	2.7	2.9	2.2bc	3.0abcd
CRP1	4.5a	3.6ab	2.1	2.1	2.5	3.3a	2.7bcd
CRP2	4.1a	3.2ab	2.8	2.9	3.1	1.3c	3.2ab
$C_4C_3$1	4.6a	4.1a	3.3	3.4	3.5	1.5bc	3.4a
$C_4C_3$2	2.3b	3.6ab	3.1	3.2	3.3	2.0bc	2.9abcd
C_4C_4	2.1b	1.7c	2.1	3.8	3.6	2.4ab	2.6bcd
C_3C_3	2.4b	2.5bc	2.7	2.8	3.0	1.7bc	2.5cd
			Streeter				
Sunburst	1.9c	1.7de	2.0	2.7	4.3a	3.8a	2.7a
Trailblazer	1.7c	1.4e	1.8	2.7	2.3bc	2.9b	2.1bc
Alkar	3.4a	2.6abc	2.3	2.9	2.4bc	1.1d	2.5ab
Haymaker	2.7b	2.7ab	3.3	2.8	2.6bc	1.6cd	2.6ab
CRP1	3.4a	2.7abc	2.7	2.6	2.8bc	1.4cd	2.6ab
CRP2	2.9b	1.7de	2.1	2.4	2.6bc	1.7cd	2.1bc
$C_4C_3$1	3.9a	3.1a	2.6	2.8	2.6bc	1.5cd	2.7a
$C_4C_3$2	1.8c	2.1bcd	2.4	2.2	3.4ab	1.8c	2.2abc
C_4C_4	1.6c	2.0cde	1.9	2.2	2.8bc	3.3ab	2.3ab
C_3C_3	1.7c	1.5de	1.8	2.1	2.2c	1.2d	1.7c

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Table 3 continued

			Williston Dryland				
Sunburst	0.8d	0.5	0.9bc	1.0	2.0	1.5a	1.1
Dakotah	0.9bcd	0.6	0.8bc	1.1	1.9	1.1bcd	1.1
Alkar	1.0bcd	0.7	1.1ab	1.1	1.6	0.8e	1.0
Haymaker	1.3a	0.8	1.3a	1.3	2.1	1.1bcd	1.3
CRP1	1.0abc	0.7	1.1ab	1.2	1.7	1.0cde	1.1
CRP2	0.8cd	0.6	0.8c	1.1	2.0	0.8de	1.0
$C_4C_3$1	1.1ab	0.7	0.9bc	1.1	1.6	0.9cde	1.0
$C_4C_3$2	0.8cd	0.8	0.8bc	1.0	1.7	1.1bc	1.1
C_4C_4	0.9bcd	0.7	1.0bc	1.1	1.9	1.3ab	1.2
C_3C_3	0.8d	0.6	0.9bc	1.0	1.7	0.9cde	1.0
			Williston Irrigated Land				
Sunburst	5.8a	7.3a	5.8a	5.4a	5.6a	5.4a	5.9a
Dakotah	4.3bc	4.9c	4.1b	4.2bc	3.9cd	3.7c	4.2c
Alkar	5.0ab	3.2e	3.8b	3.3def	3.1de	2.3ef	3.4d
Haymaker	4.2bc	3.3e	3.7b	2.5f	3.1de	2.5ef	3.2de
CRP1	4.5bc	3.3e	2.8c	3.4cde	3.2de	2.9de	3.3de
CRP2	3.7c	2.8e	3.5bc	2.8ef	2.7e	1.9f	2.9e
$C_4C_3$1	5.6a	4.3d	3.9b	3.9cd	4.7bc	4.6b	4.5c
$C_4C_3$2	5.8a	5.7b	5.7a	5.4a	5.6a	5.5a	5.6ab
C_4C_4	4.9ab	5.8b	5.0a	5.1ab	5.5ab	5.2ab	5.3b
C_3C_3	4.2bc	3.1e	3.3bc	3.4cde	3.7d	3.3cd	3.5d

[1] Experimental entry lists and abbreviations are shown in Table 1.
[2] Within columns for each site, means followed by the same letter are not significantly different at the *P* = 0.05 level.
[3] Data not available for 2008 due to reseeding.
[4] No harvest in 2011 or 2012 due to poor stand establishment.