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Biomass and Seed Yields of Big Bluestem, Switchgrass, and Intermediate Wheatgrass in Response to Manure and Harvest Timing at Two Topographic Positions

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Biomass and seed yields of big bluestem, switchgrass, and intermediate wheatgrass in response to manure and harvest timing at two topographic positions

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Abstract

A principle attribute of perennial grasses for biomass energy is the potential for high yields on marginal lands. Objectives of this study were to compare biomass and seed production of intermediate wheatgrass (*Thinopyrum intermedium* [Host] Barkworth and D.R. Dewey), big bluestem (*Andropogon gerardii* Vitman), and switchgrass (*Panicum virgatum* L.) as affected by harvest timing and manure application on two topographic positions (footslope and backslope). Footslope is the hillslope position that forms the inclined surface at the base of a slope and backslope forms the steepest, middle position of the hillslope. Grasses were harvested for biomass at anthesis (summer), after a killing frost (autumn), or the following spring after overwintering in the field. Seed was harvested at maturity during 2003 and 2004. Two rates of beef cattle (*Bos taurus* L.) manure (target rates of 0 and 150 kg total-N ha^{-1}) were surface applied annually. Maximum annual biomass yield ranged from 4.4 to 5.2, 2.7 to 4.2, and 3.7 to 5.6 Mg ha^{-1} for intermediate wheatgrass, big bluestem, and switchgrass, respectively. Biomass yields were not different between fall and spring harvest treatments. Biomass yields of big bluestem and switchgrass at the backslope position were 86% and 96% of biomass yields at the footslope position with normal precipitation, respectively. Manure application increased biomass yield approximately 30% during the second year on both topographic positions. The highest seed yield was obtained from intermediate wheatgrass, followed by switchgrass and big bluestem. Utilizing these management practices in our environment, it appears that switchgrass and big bluestem could be allowed to overwinter in the field without suffering appreciable loss of biomass.

Keywords: big bluestem, biomass, intermediate wheatgrass, landscape, manure, marginal land, switchgrass

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Introduction

Perennial warm-season (C_4) grasses, such as switchgrass and big bluestem that are native to the tall grass prairie are important for forage production, conservation, and wildlife habitat (Moser *et al*., 2004). Another important potential use for switchgrass (Sanderson *et al*., 2004a, b) and big bluestem (Mulkey *et al*., 2008) is bioenergy production. Intermediate wheatgrass, an introduced perennial cool-season (C_3) grass, is important for forage production and conservation throughout the temperate regions of North America. Intermediate wheatgrass is well adapted to areas that receive at least 350 mm of annual precipitation and is highly productive on marginal land (Asay & Jensen, 1996). Ross & Krueger (1976) reported intermediate wheatgrass had forage yielding ability higher than any other grasses in South Dakota. Water-use efficiency of warm season (C_4) grasses is higher than that of cool season (C_3) grasses because of the more efficient CO_2 uptake and transfer system of C_4 plants. Water-use efficiency of C_4 grasses ranges from 2.44 to 7.5 g DM kg^{-1} water, and C_4 grasses are about twice as productive per unit of water as C_3 grasses (Volenec & Nelson, 2007).

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Nutrients and harvest timing are important management issues for sustainable production of perennial grasses. Harvest management of warm- and cool-season grasses for bioenergy should emphasize yield and persistence but not necessarily forage quality. A feedstock producer may want to have flexible harvest times for potential fluctuations in feedstock markets (Sanderson *et al*., 2004a, b). Also, flexible harvest timing may help a farmer diversify labor requirements. Several studies have reported optimum harvest timing and frequency for maximum yield and quality of switchgrass biomass feedstock (Sanderson *et al*., 1999; Vogel *et al*., 2002; Mulkey *et al*., 2006). In general, a single harvest during autumn was recommended for maximum sustainable yield and a single harvest delayed until late autumn through winter was desirable for optimum quality of biomass feedstock. Lee & Boe (2005) suggested harvesting over-wintered switchgrass since stands could be stockpiled for conservation and wildlife without significant loss of biomass.

Warm-season grasses are adapted to a wide range of soil conditions because of their high water-use efficiency and N-use efficiency. Vogel *et al*. (2002) reported that switchgrass needs about 10–12 kg N ha^{-1} for each Mg of biomass yield in the Midwest USA. In South Dakota, the optimum N fertilization rate for biomass production and persistence of switchgrass was 56 kg ha^{-1} on Conservation Reserve Program (CRP) lands (Mulkey *et al*., 2006). Big bluestem production was comparable to switchgrass and responded to N fertilization rates up to 90 kg ha^{-1} (McMurphy *et al*., 1975; Hall *et al*., 1982). In general, cool-season grass response to N fertilization depends highly on the availability of soil moisture (Smika *et al*., 1965; Power, 1985). Power (1985) reported a nitrogen use efficiency of 51 kg DM kg^{-1} N for intermediate wheatgrass in North Dakota, USA.

Because of its nutrients and organic matter content, livestock manure is a valuable resource for soil conservation as well as crop production. By adding manure to the soil, not only can organic matter depleted by agronomic practices be restored, but nutrients such as N can be provided for crop growth. Several studies have shown that livestock manure could be a good alternate source of N for perennial grasses (Sanderson & Jones, 1997; Sanderson *et al*., 2001; Cherney *et al*., 2002; McLaughlin *et al*., 2004; Lee *et al*., 2007). Lee *et al*. (2007) also found that switchgrass stand persistence was better when manure was the source of N compared with ammonium nitrate. However, improper use of manure may result in environmental contamination of water, air, and land (Eghball & Power, 1994). Applying manure to switchgrass, with its large fibrous root system, would help limit environmental problems compared with its application in annual cropping systems (Sanderson *et al*., 2001). Furthermore, perennial forage grasses provide permanent ground cover, thus reducing sediment problems such as soil erosion and runoff (Sharpley & Halvorson, 1995).

A principal attribute of native warm-season grasses, such as switchgrass and big bluestem, is the potential for high biomass production on land not suitable for conventional row crop production (Vogel, 1996). Until now, the major income alternative for producers with marginal or highly erodible farmland has been the CRP. Production of biomass from perennial grasses on marginal land would enhance soil organic carbon, soil quality, water quality, and wildlife habitat, with the major added economic and rural community benefit of retaining sustainable agricultural systems in the northern Great Plains, USA.

Little information is available regarding biomass feedstock production potential and management strategies for warm- and cool-season grasses on marginal lands. The objectives of this study were: (1) to compare biomass and seed production potential of two perennial native warm-season grasses to an introduced perennial cool-season grass and (2) to determine the effect of harvest timing and manure application on production of these grasses on two topographic positions ranging from highly suitable to unsuitable for corn production in the northern Great Plains, USA.

Materials and methods

This experiment was conducted from 2003 to spring 2005 at the UDSA-ARS North Central Agricultural Research Laboratory Farm (96°45′W; 44°19′N) near Brookings, SD, USA. Table 1 shows monthly precipitation for 2002 through 2004 and the 30-year average at the farm. Dominant soils at the site are a Sioux gravelly loam (sandy-skeletal, mixed Udorthentic Haploborolls) on upper backslope positions and a Svea loam (fine-loamy, mixed Pachic Udic Haploborolls) on lower backslope and footslope positions, with slopes $<10\%$. Footslope is the hillslope position that forms the inner, gently inclined surface at the base of a slope and backslope forms the steepest, and generally linear, middle position of the hillslope (Fig. 1). The Sioux series is a land capability class (Helm, 1992) 6/7 and is rated not suitable for corn and wheat. The Svea series is a land capability class 1 and is rated highly suitable for corn and wheat. 'Oahe' intermediate wheatgrass (*Thinopyrum intermedium* [Host] Barkworth and D.R. Dewey), 'Bison' big bluestem (*Andropogon gerardii* Vitman), and 'Nebraska 28' switchgrass (*Panicum virgatum* L.) were planted

Table 1 Monthly precipitation for 2002 through 2004 and the 30-year average in eastern South Dakota USA

Month	2002 (mm)	2003 (mm)	2004 (mm)	30 years average (mm)
January	5.8	5.8	8.9	8.6
February	1.0	5.8	9.4	10.2
March	54.1	2.5	29.2	32.8
April	32.8	49.5	41.1	51.6
May	78.5	69.6	157.7	74.9
Jun	61.7	83.8	68.1	107.4
July	68.6	70.1	111.0	79.0
August	183.4	56.1	23.1	74.7
September	35.3	87.6	157.7	63.0
October	68.8	27.4	14.5	45.2
November	0.0	8.1	11.7	25.4
December	4.3	7.4	2.3	6.6
Total	594.4	474.0	634.7	579.4

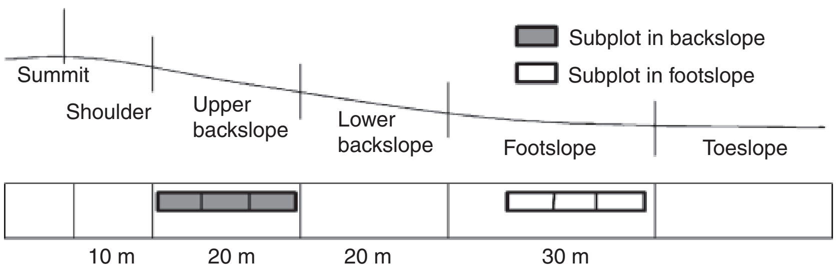

Fig. 1 Schematic diagram of experimental site, including locations and approximate dimensions of plots and sub-plots (landscape positions).

across a topographical gradient on June 8, 2001 with a Truax no-till drill with 20-cm row spacings at seeding rates of 11.0, 6.0, and 7.0 kg pure live seed ha^{-1}, respectively. Plots were not harvested or fertilized until treatments were imposed in 2003.

The experimental design was a randomized complete block in a split-split-plot arrangement of treatments with four replications. Species ($n = 3$) were treated as whole plots, harvest timing ($n = 3$) as subplots, and manure treatment ($n = 2$) as sub-sub-plots (3.3 m × 3.3 m). Treatments were replicated four times at each topographic location, backslope and footslope (Fig. 1). Harvest timing treatments included (i) anthesis (summer), (ii) biomass/seed production with seed harvest at maturity and autumn biomass harvest to a stubble height of 10–15 cm (autumn), and (iii) biomass/seed production with seed harvest at maturity and biomass harvest the following spring to a stubble height of 3–5 cm (overwinter). One-half of each sub-plot received about 150 kg total-N ha^{-1} from manure each year. The other half of each sub-plot was a control and received no manure. Approximately 2 kg manure was collected for N analysis each year. Total N concentration in manure was 11.9 and 12.4 g kg^{-1} for 2003 and 2004, respectively. Preweighed wet manure (12.6 ton DM ha^{-1} for 2003 and 12.1 ton DM ha^{-1} for 2004) was broadcast by hand onto the surface of each plot on the dates shown in Table 2.

Before biomass was harvested from autumn and overwintered plots, seed was collected from entire sub-sub-plots (3.3 m × 3.3 m). Seed of intermediate wheatgrass, big bluestem, and switchgrass was harvested on August 20, September 2, and September 30, 2003, respectively. In 2004, intermediate wheatgrass seed was harvested on September 17 while big bluestem and switchgrass seed was not harvestable because of freezing temperatures during seed development. Inflorescences of intermediate wheatgrass and switchgrass were excised with pruning shears, threshed using a small grain head thresher, and screened by hand to remove rachis and panicle fragments. Inflorescences of big bluestem were removed by hand, threshed on a rubber rub-board, and screened by hand to remove rachis fragments. Fertile florets of switchgrass were separated from the remaining inert matter with a South Dakota style of seed blower

Table 2 Manure application and harvest dates for intermediate wheatgrass, big bluestem, and switchgrass during 2003 and 2004 in eastern South Dakota USA

Treatment	Manure Applied	Biomass harvest timing		
		Summer	Autumn	Overwinter
2003				
Intermediate wheatgrass	June 30	June 30	August 20	March 31, 2004
Big bluestem	June 11	July 18	September 2	March 31, 2004
Switchgrass	June 11	July 29	September 30	March 31, 2004
2004				
Intermediate wheatgrass	April 4	June 21	September 17	April 14, 2005
Big bluestem	May 3	July 20	November 4	April 14, 2005
Switchgrass	May 3	August 2	November 4	April 14, 2005

(Seedburo Equipment Co., Chicago, IL, USA). Pure seeds of intermediate wheatgrass and big bluestem were determined by a certified seed technician in the South Dakota State University Seed Testing Laboratory. Grass biomass remaining after seed production was harvested from entire sub-sub-plots with a sickle-bar mower on the dates shown in Table 2. Big bluestem and switchgrass were harvested at a cutting height of 10–15 cm for summer and autumn harvest treatments and at a cutting height of 3–5 cm for the spring harvest treatment. Intermediate wheatgrass was harvested at a cutting height of 3–5 cm for all harvest treatments. Harvested biomass was weighed fresh in the field. Dry matter yield was determined for each sub-sub-plot by collecting a random grab-subsample (about 1 kg) of harvested biomass, drying in a forced-air oven at 60 °C for 72 h, and reweighing. Weight of inflorescences and seeds were included in calculation of total biomass yield for the autumn and overwintered treatments.

Statistical analyses were conducted using JMP software (SAS Institute Inc., Cary, NJ, USA). Total biomass yield was analyzed separately by harvest year and topographical location using a split-split-plot design with species as whole plots, harvest timing as sub-plots, and fertility as sub-sub-plots. For seed yield analysis, harvest timing was not included in 2003 since this was the first year of the treatment and all seed was harvested at physiological maturity. Thus, fertility was treated as sub-plots with eight replications instead of four replications in 2003. In 2004, harvest timing was treated as a whole plot, fertility was treated as a sub-plot, and species was not included since only intermediate wheatgrass seed was harvested. All effects, other than replication, were considered fixed. Fisher's protected least significance difference was used to separate means when F tests were significant ($P<0.05$).

Table 3 Mean squares for sources of variation for biomass yields of intermediate wheatgrass, big bluestem, and switchgrass in response to harvest timing and fertility on two landscape positions in eastern South Dakota USA

Source of variation	df	2003		2004	
		Backslope	Footslope	Backslope	Footslope
Block	3	18.19	5.10	42.36	9.06
Species (Sp)	2	19.11*	19.65**	19.26	13.26*
Error *a*	6	3.41	1.08	5.52	2.15
Harvest timing (HT)	2	4.49*	2.94*	5.08*	8.85*
HT × Sp	4	2.85	3.16**	0.47	2.00
Error *b*	18	1.20	0.56	0.99	1.94
Fertility (Fert)	1	0.20	0.09	23.11***	27.78***
Sp × Fert	2	0.33	0.60	0.26	0.43
HT × Fert	2	0.12	0.15	0.02	0.05
Sp × HT × Fert	4	0.15	0.55	0.47	1.52
Error *c*	27	0.13	0.26	10.78	36.82

*,**,***Significant at the 0.05, 0.01, and 0.001 levels, respectively.

Results

Species

Maximum annual production was obtained from footslope positions, ranging from 5.0 to 5.9, 2.6 to 4.8, and 4.1 to 6.2 $Mg\,ha^{-1}$ for intermediate wheatgrass, big bluestem, and switchgrass, respectively. Biomass yields were significantly different among species at both landscape positions for both years (Table 3). On backslopes in 2003, intermediate wheatgrass and switchgrass had higher biomass yields than big bluestem, while intermediate wheatgrass produced more than switchgrass which was higher yielding than big bluestem on footslopes (Fig. 2). In 2004, switchgrass produced more biomass than either intermediate wheatgrass or big

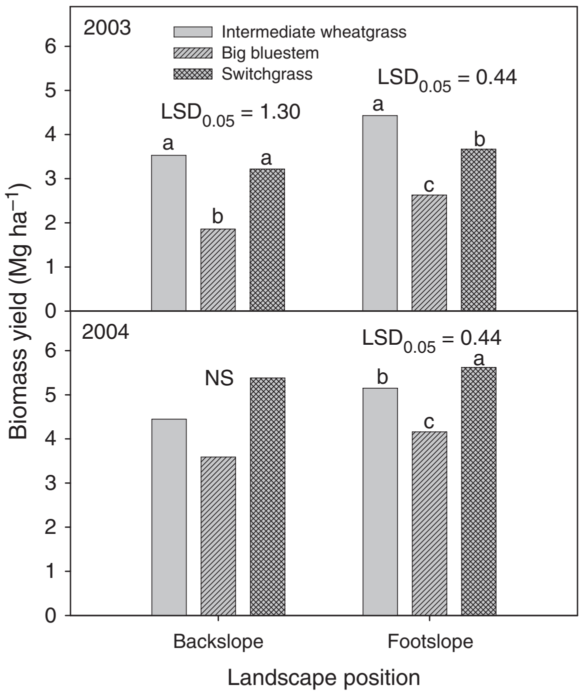

Fig. 2 Biomass yield of intermediate wheatgrass, big bluestem, and switchgrass on two landscape positions in 2003 and 2004 in eastern South Dakota, USA. Values are averaged across harvest timing and manure application. Means with the same letter in each landscape position and year are not significantly different at the 0.05 level of probability. NS = not significant.

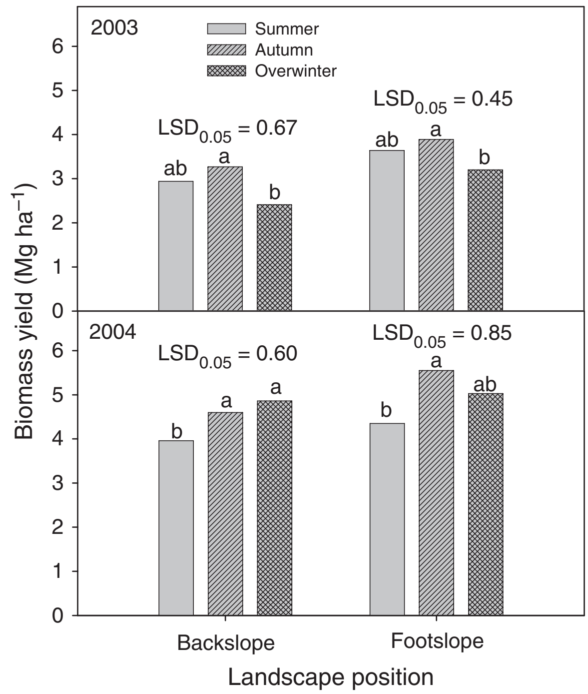

Fig. 3 Harvest timing effect on biomass yield on two landscape positions in 2003 and 2004 in eastern South Dakota, USA. Values are averaged across grass species and manure application. Means with same the letter in each landscape position and year are not significantly different at the 0.05 level of probability.

bluestem on both landscape positions (Fig. 2). Average biomass production of switchgrass and big bluestem was 60% and 73% higher, respectively in 2004 compared with 2003 while intermediate wheatgrass production was only 20% higher in 2004 than in 2003.

Harvest timing

Biomass yield was significantly affected by harvest timing at both landscape positions in 2003 and 2004 (Table 3). In 2003, biomass production was not different between summer and autumn harvest treatments, but yield of overwintered biomass was lower than during the previous autumn (Fig. 3). Biomass yields were not different between fall and overwintered harvest treatments in 2004 (Fig. 3).

Biomass yields of overwintered switchgrass harvested at a 3–5 cm stubble height were about 10% lower but not different from biomass harvested at a 10–15 cm stubble height the previous autumn whereas big bluestem production was similar for autumn and overwintered harvest treatments (Fig. 4).

Manure application

Manure application had no effect on biomass production in 2003. However, application of manure increased biomass yields on both landscape positions in 2004 (Table 3 and Fig. 5). Biomass yields increased by 30% and 28% with manure on backslope and footslope positions in 2004, respectively.

Seed production

Seed yields were significantly different among species in 2003 (Table 4), averaging 197, 108, and 43 kg ha^{-1} for intermediate wheatgrass, switchgrass, and big bluestem, respectively (Fig. 6). Maximum seed yields in 2003 for intermediate wheatgrass, big bluestem, and switchgrass were obtained on footslopes and were 242, 51, and 119 kg ha^{-1}, respectively (Fig. 6). Seed yield of intermediate wheatgrass, big bluestem, and switchgrass on backslopes was 61%, 69%, and 80% of seed yield on footslopes, respectively. Seed yield was not affected by manure application during 2003. In 2004, seed of big bluestem and switchgrass was not harvestable because of freezing temperatures during seed development.

Seed yields of intermediate wheatgrass in 2004 were affected by harvest timing on footslopes and by manure on backslopes (Table 5). Seed yield was higher in manure-treated plots (82 kg ha^{-1}) than in control plots (35 kg ha^{-1}) on backslopes, but was not affected by manure application on footslopes. Seed yield of fall harvested plots (79 kg ha^{-1}) was higher than in overwintered plots (56 kg ha^{-1}) on footslope positions, and a similar trend was noted on backslopes despite the fact that seed was harvested at the same time from both autumn and overwintered plots.

Discussion

There was a species × harvest timing interaction for biomass production in 2003 at the footslope position (Table 3). The principle reason for this interaction was the decreased yield of overwintered compared with autumn-harvested intermediate wheatgrass (Fig. 4). In contrast, biomass production remained relatively constant from autumn to the following spring in both switchgrass and big bluestem. No other interactions were present in 2004 at either topographic position nor at the backslope position in 2003. Therefore, main effects of species, harvest timing, and manure application will be primarily discussed.

Table 4 Mean squares for sources of variation for seed yields of intermediate wheatgrass, big bluestem, and switchgrass in response to fertility treatment on two landscape positions in 2003 in eastern South Dakota USA

Source of variation	df	Backslope	Footslope
Block	7	5987	8422
Species (Sp)	2	45 856**	146 222**
Error *a*	14	4475	7342
Fertility (Fert)	1	54	91
Sp × Fert	2	0	637
Error *b*	21	462	1169

**Significant at the 0.01 levels.

The yield advantage of switchgrass in 2004 may have been the result of greater precipitation during May of that year (Table 1). Lee & Boe (2005) reported a strong linear relationship between April through May precipitation and maximum biomass yield of switchgrass in central South Dakota, USA. On the other hand, grass stands were 5 years old in 2004 which may have limited intermediate wheatgrass production in particular since this species may lose vigor after 4 or 5 production years (Asay & Jensen, 1996).

Switchgrass yields in our study were lower than those reported in other work in the Great Plains, USA (Lee & Boe, 2005; Schmer *et al*., 2008). This is likely due to choice of cultivar since Nebraska 28 has somewhat lower yield potential (Tober *et al*., 2007) than the highest yielding cultivars (e.g., 'Sunburst') adapted to the northern Great Plains, USA; and to the fact that yields were generally lower on backslope positions, i.e. marginal land. Biomass yield on backslopes was 80%, 71%, and 88% of that on footslopes for intermediate

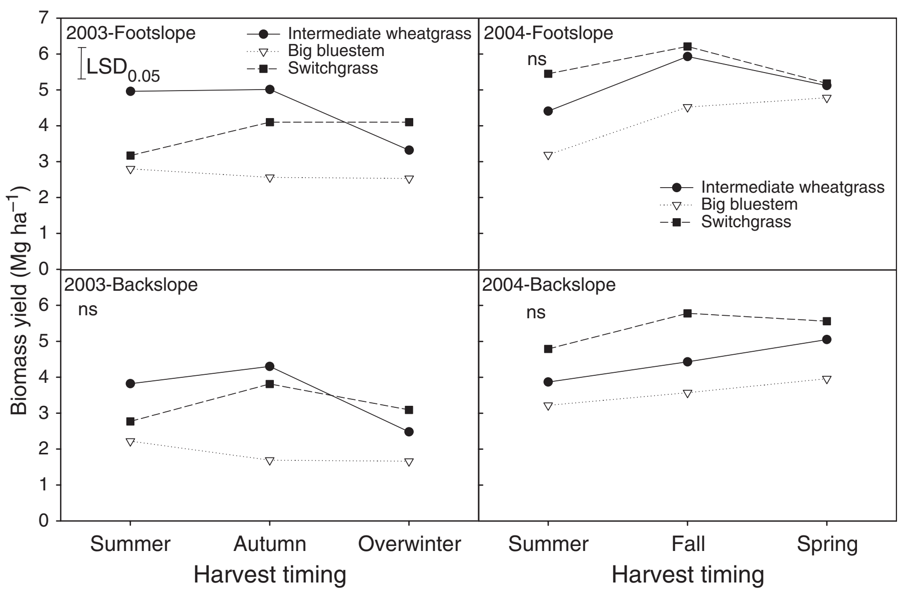

Fig. 4 Harvest timing effect on biomass yield of intermediate wheatgrass, big bluestem, and switchgrass on two landscape positions in 2003 and 2004 in eastern South Dakota, USA. Values are averaged across manure application. NS = not significant at 0.05 level of probability.

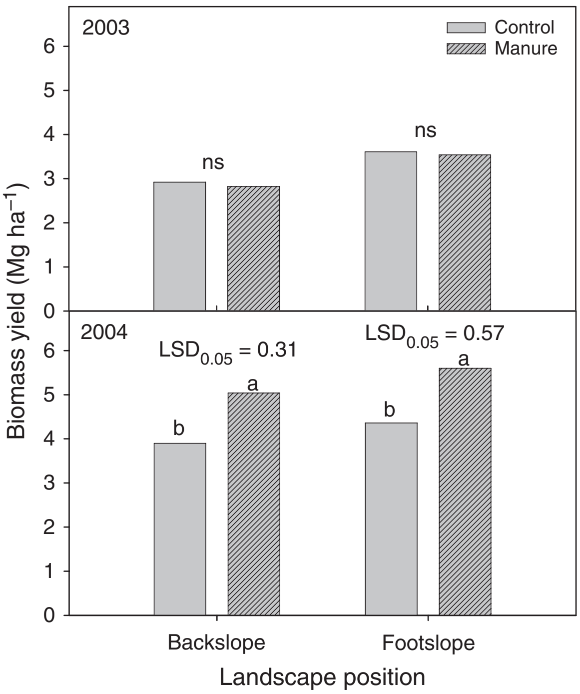

Fig. 5 Manure application effect on biomass yield on two landscape positions in 2003 and 2004 in eastern South Dakota, USA. Values are averaged across grass species and harvest timing. Means with the same letter in each landscape position and year are not significantly different at the 0.05 level of probability.

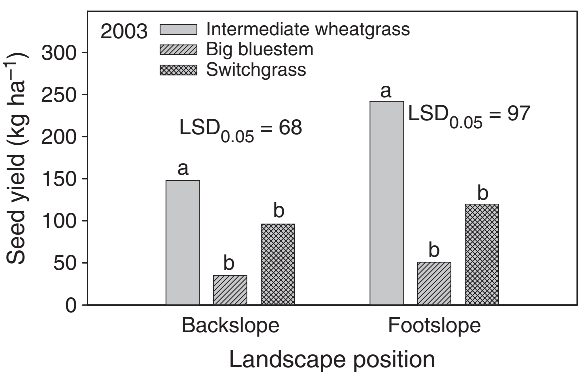

Fig. 6 Seed yield of intermediate wheatgrass, big bluestem, and switchgrass on two landscape positions in 2003 in eastern South Dakota, USA. Values are averaged across harvest timing and manure application. Means with same the letter in each landscape position and year are not significantly different at the 0.05 level of probability. NS = not significant.

wheatgrass, big bluestem, and switchgrass in 2003, respectively. In comparison, biomass yield on backslopes was 86%, 86%, and 96% of that on footslopes for intermediate wheatgrass, big bluestem, and switchgrass in 2004, respectively. The increase in the ratio of backslope to footslope biomass production was presumably related to precipitation since 390% more rainfall was received in 2004 than 2003. In comparison, Harmoney *et al*. (2001) reported that dry matter yield of grass forage on backslopes was 74% of that on summits and 52% of that on toeslopes when a mixture of 11 legumes was interseeded into perennial grass stands. Our results indicate that when sufficient early spring precipitation is received, native warm-season grasses may produce considerable biomass even on soils rated unsuitable for corn or wheat.

Table 5 Mean squares for sources of variation for seed yield of intermediate wheatgrass in response to harvest timing and fertility treatments on two landscape positions in 2004 in eastern South Dakota USA

Source of variation	df	Backslope	Footslope
Block	3	865	1534**
Harvest timing (HT)	1	484	1598**
Error *a*	3	1712	64
Fertility (Fert)	1	8836**	14
HT × Fert	1	56	2730
Error *b*	6	558	1021

**Significant at the 0.01 levels.

The reduction in yield of overwintered grass in 2003 was caused primarily by intermediate wheatgrass (Fig. 4). September and October precipitation was 33% lower in 2003 than in 2004 and intermediate wheatgrass, a cool-season species, may not have received adequate precipitation to regrow during late summer and early autumn. Consequently, yield of overwintered biomass would also be lower than anticipated. However, yields of intermediate wheatgrass did not decrease during winter 2004–2005 which was likely a result of (1) increased fall growth due to higher precipitation and (2) early growth of intermediate wheatgrass the following spring due to a weather-delayed harvest of overwintered biomass (Table 2).

Lee & Boe (2005) found that biomass loss in overwintered switchgrass could be compensated for by harvesting near ground level to include the high concentration of biomass in the basal phytomers. High biomass yield of overwintered big bluestem relative to the previous autumn was likely due to its morphology. Big bluestem has a high vegetative/reproductive tiller ratio (Mitchell *et al*., 1998) and large numbers of short basal internodes (Rechenthin, 1956), many of which would not be harvested when cut at a height of 10–15 cm during the autumn harvest.

The lack of response of any of the grasses to manure in 2003 was likely due to time of application and availability of nutrients. In 2003, manure was applied to switchgrass and big bluestem on June 11, but was not applied to intermediate wheatgrass until immediately after the summer harvest on June 30 (Table 2). In addition, even though manure was applied to switchgrass and big bluestem earlier in the season, surface broadcasting of manure during a hot/dry season may limit nutrients available for plant growth. Sanderson & Jones (1997) found that manure did not significantly increase bermudagrass (*Cynodon dactylon* L. Pers.) forage yield in the first year of application because of slow mineralization of N in the solid manure applied. They also reported that forage yields responded greatly to manure application during the subsequent 3 years. A similar result was reported for switchgrass by Sanderson *et al*. (2001). Manure application combined with commercial N fertilizer may be recommended to obtain high biomass yield in the first and second years for perennial grasses. Cherney *et al*. (2002) reported that dry matter yields of orchardgrass (*Dactylis glomerata* L. 'Okay') and tall fescue (*Festuca arundinaceae* Schreb. 'Stagrazer') receiving dairy manure were similar to that of grasses receiving commercial N fertilizer after 2 years of manure application, and residual effects of manure were maintained at least 3 years following application.

Seed yield of switchgrass and big bluestem was similar to that reported by others. In 2003, Boe (2007) reported switchgrass seed yields of 159 $kg\,ha^{-1}$ in northeastern South Dakota, USA. Switchgrass seed yields of 60–560 $kg\,ha^{-1}$ have been reported in Pennsylvania, USA (Sanderson *et al*., 2004a, b). They also reported big bluestem seed yield of 4–68 $kg\,ha^{-1}$. Seed yield of big bluestem averaged 112 $kg\,ha^{-1}$ on dryland in the northern Great Plains, USA (Boe *et al*., 2004). The significant decrease in intermediate wheatgrass seed yield from 2003 to 2004 probably was caused by a reduction in stand vigor since this species was 5 years old in 2004. Five-year-old stands of intermediate wheatgrass do not generally produce high amounts of seed (Asay & Jensen, 1996).

Intermediate wheatgrass, big bluestem, and switchgrass have potential for bioenergy feedstock production on marginal land in eastern South Dakota, USA. With near normal precipitation, these species produced comparable amounts of biomass on marginal land (rated not suitable for corn or wheat production) and on good cropland (rated highly suitable for corn and wheat production). Intermediate wheatgrass stand vigor had declined by the fifth production year (2004) as noted by decreases in both biomass and seed yields.

Big bluestem and switchgrass produced maximum biomass when they were harvested during autumn, but differences between autumn-harvested and overwintered biomass were not significant. This finding is important for this region in particular since overwintering of biomass would be highly desirable for wildlife habitat and conservation purposes. Given the fact that harvesting of traditional row crops, such as corn and soybeans, occurs during autumn, extending the harvest window for switchgrass and big bluestem to the following spring would also help alleviate conflicts with equipment and time. In contrast to switchgrass and big bluestem, biomass yield of intermediate wheatgrass tended to decrease when it was allowed to overwinter.

Manure application for biomass and seed production of perennial grasses could be used as an alternative to commercial fertilizer. The positive effect of manure becomes evident during the second year of application. Seed production of these grasses was inconsistent between years, but seed of bioenergy crops would be another potential income stream for diversified farming operations in the northern Great Plains, USA.

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