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Do Introduced Grasses Improve Forage Production on the Northern Mixed Prairie?

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Abstract

Relative benefit of introducing forage species to the Northern Great Plains have been examined with contradictory conclusions. In most cases, studies were either confounded by time of establishment or treatments were not randomized and lacked independence. We examined aboveground net primary production (ANPP) in northern mixed prairie using a randomized complete block design with four treatments: crested wheatgrass (*Agropyron cristatum* [L.] Gaertn.), Russian wildrye (*Psathyrostachys juncea* [Fisch.] Nevski), a native control that was not harvested, and a harvested native. The experiment was conducted in a *Stipa–Agropyron–Bouteloua* site and a *Stipa–Bouteloua* site over 13 yr and 12 yr, respectively. The data were analyzed by sampling period (*Stipa–Agropyron–Bouteloua*: 1, 1994 to 1997; 2, 1998 to 2001; 3, 2002 to 2006; and *Stipa–Bouteloua*: 1, 1995 to 1998; 2, 1999 to 2002; 3, 2003 to 2006). ANPP among treatments was influenced ($P < 0.05$) by site and its interaction with treatment and sampling period (1 to 3). ANPP from the native-control, harvested-native, crested wheatgrass, and Russian wildrye treatments was 220.9, 183.9, 300.8, and 189.6 $g \cdot m^{-2}$ (SEM = 11.2), respectively, in the *Stipa–Agropyron–Bouteloua* site and 122.9, 98.2, 216.3, and 115.9 $g \cdot m^{-2}$ (SEM = 12.0), respectively, in the *Stipa–Bouteloua* site. Mean ANPP (SEM) within each sampling period (1 to 3) was 186.4 (9.1), 135.4 (5.8), and 263.9 (8.8) $g \cdot m^{-2}$ in the *Stipa–Agropyron–Bouteloua* site, respectively, and 124.5 (6.4), 138.6 (6.1), and 151.3 (10.5) $g \cdot m^{-2}$ in the *Stipa–Bouteloua* site, respectively. Russian wildrye in the *Stipa–Bouteloua* site and crested wheatgrass in both sites was relatively more productive in the first period after establishment than in subsequent years. The study confirms the relative ANPP advantage of crested wheatgrass over native on the *Stipa–Bouteloua* site but not on the *Stipa–Agropyron–Bouteloua* site, whereas Russian wildrye exhibited no ANPP advantage over the native on either site.

Resumen

Los beneficios relativos de introducir especies de forraje en las Grandes Planicies del Norte han sido examinados en estudios bien conocidos con la conclusión contradictoria. En la mayoría de los casos, la investigación se llevo a cabo en estudios que fueron confundidos por el tiempo del establecimiento ó donde los tratamientos no pudieron ser al azar, y por lo tanto, carecieron de independencia. Por consiguiente, el tema ha permanecido controversial, lo cual ha impulsado un estudio para reexaminar la productividad relativa entre las especies agronómicas introducidas comúnmente en dos sitios de pradera mixta en las Grandes Planicies del Norte. Nosotros examinamos la producción primaria neta sobre el terreno (ANPP), y la biomasa cosechada en un diseño de bloques completos al azar con cuatro tratamientos representados por dos monocultivos de pasto introducido: (*Agropyron cristatum* [L.] Gaertn, triguillo crestado y *Psathyrostachys juncea* [Fisch.] Nevski, centeno salvaje ruso), y dos comunidades de plantas nativas (control-nativo sin cosechar y cosechado–nativo). El experimento se repitió, tanto en un sitio de *Stipa–Agropyron–Bouteloua* y un sitio más seco de *Stipa–Bouteloua* durante 13 y 12 años, respectivamente, desde el momento del establecimiento. El ANPP y la biomasa cosechada entre los tratamientos fue influenciada ($P < 0.05$) por el sitio y su interacción con el tratamiento y el periodo de muestreo. Con excepción de la *P. juncea* en el sitio de *Stipa–Bouteloua*, los pastos introducidos fueron relativamente más productivos en los primeros años después del establecimiento que en los años posteriores. Después de este periodo, *A. cristatum* produjo rendimientos similares como el cosechado–nativo en el sitio de *Agropyron–Bouteloua* pero sobre 1.75 veces más que en el sitio de *Stipa–Bouteloua*. *P. juncea* generalmente produjo menos ($P < 0.05$) ó similar ($P > 0.05$) ANPP como el sitio de cosechado–nativo. El pasto introducido produjo una proporción mayor ($P < 0.05$) de ANPP cosechado más que el cosechado–nativo en ambos sitios. El estudio confirma la ventaja relativa de ANPP del *A. cristatum* sobre el nativo en el sitio de *Stipa–Bouteloua* pero no en el sitio de *Stipa–Agropyron–Bouteloua*.

Key Words: aboveground net primary production, *Agropyron cristatum*, native, *Psathyrostachys juncea*

INTRODUCTION

Native semiarid grasslands in western Canada have been extensively cultivated and seeded to introduced grasses or cropped for cereal production over the past 100 yr. On the mixed prairie, the seeded grasses consisted mostly of crested wheatgrass (*Agropyron cristatum* [L.] Gaertn.) and Russian wildrye (*Psathyrostachys juncea* [Fisch.] Nevski). Replacement of native plant communities with monocultures of introduced grasses was encouraged with promises of increased agricultural production and supported by studies reporting greater forage production, which resulted in six times more beef (Smoliak and Slen 1974) and about three times more sheep (Smoliak 1968) produced than from native grasslands. However, Black (1968) reported greater production from native rangeland than from crested wheatgrass in northeastern Montana.

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Table 1. Average growing season (April to September inclusive) precipitation and temperature for each sampling period and their 30-yr averages at two sites.

Stipa–Agropyron–Bouteloua			*Stipa–Bouteloua*		
Period	Temperature (°C)	Precipitation (mm)	Period	Temperature (°C)	Precipitation (mm)
1 (1994–1997)	13.6	281	1 (1995–1998)	14.4	265
2 (1998–2001)	14.5	229	2 (1999–2002)	14.1	249
3 (2002–2006)	13.9	357	3 (2003–2006)	14.7	230
30-yr average	13.7	282	30-yr average	14.0	244

Native grasslands exhibit high species diversity that might be expected to benefit the survival of the community and maximize production stability. Furthermore, a large portion of net primary production is found belowground (Coleman et al. 1976), which is believed to contribute to nutrient conservation and the capture of limited soil moisture. Concerns about the practice were challenged by studies comparing the productivity of introduced agronomic species with those of selected native species grown in cultivated and seeded plots (Lawrence and Troelson 1964; Lawrence 1978; Kilcher and Looman 1983). With a few exceptions, results from such studies often favored the introduced species, although the comparisons were strongly influenced by variation in stand establishment and the timing and frequency of harvest (Jefferson et al. 2005).

Relatively few studies have been reported comparing the productivities of native communities with seeded communities of introduced grasses. Of those, most are not based on randomized treatments, but rather on sampling pre-existing conditions, and comparisons are made across previously established borders, thereby violating the assumption of statistical independence. There is also a discrepancy in response among sites that appears to be determined by their moisture regime. For example, Johnston et al. (1968) reported about four times more forage was produced on the more mesic fescue prairie dominated by rough fescue (*Festuca campestris* Rydb.) than on nearby grassland seeded to smooth brome (*Bromus inermis* Leyss.), whereas Smoliak (1968) reported greater forage production from grasslands seeded to crested wheatgrass than from native grassland in the more xeric mixed prairie.

These issues present uncertainties in addressing the question of what effect converting native grassland to introduced grasses has had on aboveground net primary production (ANPP). Therefore, we initiated a long-term study to examine that question and to ascertain the nature of ANPP response following cultivation of native grassland soil and establishing communities of introduced grasses. To do that, we examined how ANPP is affected by time since establishment. We tested the hypotheses that native plant communities were equally productive to those of introduced grasses and that complex native communities exhibit greater production stability than seeded monocultures.

METHODS

Site Description

The study was conducted at two mixed prairie sites that had not been previously cultivated. One site was located at the Agriculture and AgriFood Canada substation at Onefour (lat 110°29′W, long 49°07′N) in a *Stipa–Bouteloua* community, and the second site was near Lethbridge (lat 112°57′W, long 49°43′N) in a *Stipa–Bouteloua–Agropyron* community. The *Stipa–Bouteloua* community is located in the more xeric Dry Mixed Grass Ecoregion; the *Stipa–Bouteloua–Agropyron* community is located in the more mesic Mixed Grass Ecoregion (Strong and Leggat 1992). The vegetation at these sites has been described by Coupland (1961). The *Stipa–Bouteloua* community is defined by needleandthread (*Hesperostipa comata* [Trin. & Rupr.]) and blue grama (*Bouteloua gracilis* [Willd. ex Kunth] Lag. ex Griffiths); whereas the *Stipa–Bouteloua–Agropyron* community is defined by needle-and-thread, western wheatgrass (*Pascopyrum smithii* [Rydb.] A. Löve), and blue grama.

The soils of the *Stipa–Agropyron–Bouteloua* community were Dark Brown Chernozemic and had a loamy texture. Long-term average annual precipitation was 396 mm with 30% falling in May and June. Average long-term monthly temperature from April to September was 13.7°C. The soils of the *Stipa–Bouteloua* community were Brown Chernozemic with a loamy-clay texture. Long-term average annual precipitation was 352 mm per year with 31% of that occurring in May and June. Average long-term monthly temperatures from April to September were 14.0°C.

Both sites had been summer-grazed at light to moderate stocking rates (Wroe et al. 1981) for at least 10 yr before the study was implemented in 1993. Air temperature and precipitation were recorded at meteorological stations located within 10 km of each site and reported in three periods for each site (Table 1). These stations were assumed to represent the monthly climate at the experimental sites because both stations and their paired experimental sites were surrounded by similar environments, and the weather systems at each site are not affected by predictable convection patterns.

Field and Laboratory

The studies began in 1993 and 1994 at the *Stipa–Agropyron–Bouteloua* and *Stipa–Bouteloua* sites, respectively. Exclosures (60 × 35 m) were built at each site with cattle-, wildlife-, and small rodent-proof fence. A 5-m buffer was placed between the fence and plot area as well as between blocks. The experiment was established in a randomized complete block design with four blocks and seven treatments each in 3 × 10 m plots. Here we report only on the results from four treatments that included seeded monocultures of crested wheatgrass var. Parkway and Russian wildrye var. Cabree, native grassland that was harvested annually (harvested native), and a native grassland that was not harvested (native control). Seeded plots were established by cultivating using a rotary tiller to a depth of 10 cm at the time the trials were established. The action was repeated several times in the spring and the plots were hand-weeded to remove live rhizomes and plant crowns. The plots were seeded in June of the same year with 15-cm row spacing. All treatments, with the exception of the native control, were cut annually beginning in the year after seeding to simulated grazing in order to compare productivities under more realistic conditions. Neither fertilizer nor supplemental water was added to the plots.

Estimates of ANPP were determined from the first year after seeding by sampling one 0.25-m^2 (0.5 $\times$ 0.5 m) quadrat at peak standing crop in early July or August before harvesting. The treatments were sampled at ground level and the litter (dead plant tissue) was hand separated from the green herbage to estimate ANPP. The harvested native and the agronomic treatments were then harvested with a flail forage harvester at a height of 8 cm. The sampled quadrats were re-examined in September for evidence of regrowth, which was subsequently cut and added to the ANPP. The quadrats were located systematically to avoid repeated sampling among years. All biomass was oven-dried at 60°C and weighed. Crested wheatgrass was sampled about 1 mo earlier than the remaining treatments because of its earlier phenological development.

Species composition of the native treatments was sampled in 2006 using four 20 $\times$ 50 cm quadrats per plot. The quadrats were spaced 1 m apart on a transect centered in each plot. The percent canopy cover of each species was determined using ocular estimates to the nearest 5% cover. The accuracy of ocular estimates was improved with the aid of a frame marked with a grid.

Statistical Analyses

The durations of the trials, beginning with the first year after seeding, were 13 yr and 12 yr for the *Stipa–Agropyron–Bouteloua* and *Stipa–Bouteloua* sites, respectively. This time was divided into three periods of 4 yr, 4 yr, and 4 or 5 yr to simplify the interpretation of a possible time since establishment $\times$ treatment effect on ANPP. We assumed that enhanced mineralization resulting from cultivation would be more pronounced in the first 4 yr and reach stability in the later years. ANPP was analyzed first with the whole model consisting of site, period, treatment, and replicate using Proc Mixed (SAS 2005) to test the effect of site and its interaction with the main factors. Period was treated as a repeated measure. Four covariance matrices (autoregressive, heterogeneous autoregressive, compound symmetry, and heterogeneous compound symmetry) were tested with the Akaike's Information Criterion to select the best structure. A significant ($P < 0.05$) site $\times$ treatment interaction justified a second analysis conducted by site with all other factors remaining the same. Treatment means were separated using Fisher's protected LSD test at $P = 0.05$.

Production stability among years was estimated for each treatment with the coefficient of variation (CV; %) of the ANPP. Only years of the second and third periods were used to avoid the cultivation effect. The data were normally distributed according to the Shapiro–Wilk W statistic ($P = 0.495$; Proc Univariate; SAS 2005) and transformations were not required prior to analysis of variance. The CV values among treatments were analyzed (Proc Mixed; SAS 2005) with treatment $\times$ replicate as the error term.

The relationship of ANPP to time since establishment was assessed relative to the native control in order to determine the cultivation effect. The ANPP of the native control was subtracted from individual treatments and the result was plotted against years since establishment ($x = 0 =$ first year after seeding) to visually determine the likely model. The data generally followed a decay function described by the model $Y = a + c\ e^{-bx}$ (Proc Nlin; SAS 2005), where a is the lower asymptote, c + a is the intercept on the Y axis (where $x = 0$), b is the decay coefficient, and x is the number of years since establishment. When this model was not significant ($P > 0.05$), the data were fitted to a linear equation (Proc Reg; SAS 2005).

RESULTS

The native control in the *Stipa–Agropyron–Bouteloua* site was dominated by western wheatgrass whereas pasture sage (*Artemisia frigida* Willd.) had a greater ($P < 0.05$) canopy cover in the harvested native than the native control (Table 2). The canopy cover of all species in the *Stipa–Bouteloua* site was similar ($P > 0.05$) between the native control and harvested control.

ANPP and harvested biomass among treatments was influenced ($P < 0.05$) by site and its interaction with treatment and sampling period; therefore, only the analysis by site is presented here. The treatments responded differently ($P < 0.05$) among periods on both the *Stipa–Agropyron–Bouteloua* and *Stipa–Bouteloua* sites (Table 3). Crested wheatgrass was the most productive in the first 4 yr after establishment on both sites, but ANPP was similar ($P > 0.05$) to the native control and harvested native in each subsequent period on the *Stipa–Agropyron–Bouteloua* site (5 to 13 yr after establishment), and showed similar yields ($P > 0.05$) to the native control in the third period (9 to 12 yr after establishment) on the *Stipa–Bouteloua* site (Table 3). Russian wildrye was the least ($P < 0.05$) productive on the *Stipa–Agropyron–Bouteloua* site in each period and one of the least productive in the second and third periods on the *Stipa–Bouteloua* site (Table 3). The CV values of ANPP over years were similar among all treatments at both sites.

ANPP differences from the native control were described ($P < 0.05$) by the exponential model for crested wheatgrass at both sites and for the harvested native in the *Stipa–Bouteloua* site (Fig. 1). Russian wildrye followed a linear regression ($P < 0.05$) at both sites, whereas the productivity of the harvested native declined immediately below that of the native control after harvesting in the *Stipa–Bouteloua* site. The relative ANPP of crested wheatgrass declined more rapidly at the *Stipa–Agropyron–Bouteloua* site than the *Stipa–Bouteloua* site (Fig. 1).

DISCUSSION

Production comparisons are often made with the native community because it represents the original forage type that

Table 2. Percent canopy cover of the native-control (Cont.) and harvested-native (Harv.) plots of the *Stipa–Agropyron–Bouteloua* and *Stipa–Bouteloua* sites in 2006 ($n = 4$).

	Stipa–Agropyron–Bouteloua				*Stipa–Bouteloua*			
	Cont.	Harv.	SE	*P*	Cont.	Harv.	SE	*P*
Graminoids								
Bouteloua gracilis (Willd. ex Kunth) Lag. ex Griffiths	17.8	19.1	5.9	0.735	20.0	27.5	6.8	0.498
Calamagrostis montanensis Scribn. ex Vasey	0.0	0.0	—	—	2.2	4.0	1.4	0.368
Carex spp.	33.4	39.1	9.0	0.762	13.1	17.8	4.1	0.410
Elymus lanceolatus (Scribn. & J. G. Sm.) Gould	0.0	1.2	0.9	0.359	0.0	0.0	—	—
Hesperostipa comata (Trin. & Rupr.) Barkworth	15.3	21.2	5.4	0.410	58.8	47.5	4.3	0.118
Koeleria macrantha (Ledeb.) J. A. Schultes	0.0	2.2	1.6	0.356	2.1	4.6	1.9	0.468
Pascopyrum smithii (Rydb.) A. Löve	76.9	43.1	8.2	0.026	17.2	22.4	9.2	0.498
Poa secunda J. Presl	0.0	0.8	0.5	0.356	0.6	0.0	0.4	0.356
Forbs								
Achillea millefolium L.	2.2	0.0	1.9	0.356	0.0	0.0	—	—
Artemisia frigida Willd.	3.8	35.0	10.4	0.045	2.8	2.5	2.4	0.872
Lygodesmia juncea (Pursh) D. Don ex Hook.	0.0	0.0	—	—	1.6	1.2	0.9	0.931
Plantago patagonica Jacq.	0.0	0.0	—	—	0.1	0.4	0.3	0.657
Sphaeralacia coccinea (Nutt.) Rydb.	0.6	0.3	0.5	0.780	1.9	0.2	1.4	0.491
Shrubs								
Krascheninnikovia lanata (Pursh) A. D. J. Meeuse & Smit	8.1	1.6	3.5	0.353	0.9	0.0	0.6	0.356

was replaced with "improved" introduced grasses. Although other studies have compared native and introduced grass communities, this study is unique in that the comparisons begin at the time of establishment in previously unbroken native grassland and the experimental error is controlled through a randomized complete block design where the undisturbed native community was maintained in situ.

Our study does not unconditionally support the previous claims of improved productivity from introduced grasses (Smoliak 1968; Smoliak and Slen 1974; Kilcher and Looman 1983) because their relative performance was affected by species, time since establishment, and site. Furthermore, the relative productivity of native grasslands is strongly influenced by their defoliation regime (Holechek et al. 2001). Therefore,

Table 3. Aboveground net primary production (ANPP) of native communities and monocultures of seeded introduced species during three periods after establishment at a *Stipa–Agropyron–Bouteloua* and a *Stipa–Bouteloua* site over 13 yr or 12 yr, respectively, on previously unbroken land. The effects of site, and its first order interactions with treatment and period on ANPP were significant ($P \leq 0.001$). In a test by site, the effects of period, treatment, and their interaction were significant at the *Stipa–Agropyron–Bouteloua* ($P < 0.001$, < 0.001, and < 0.001, respectively) and the *Stipa–Bouteloua sites* ($P < 0.001$, 0.017, and < 0.001, respectively). The coefficient of variation (CV) values across treatments were not significantly different at the *Stipa–Agropyron–Bouteloua* ($P = 0.407$) and the *Stipa–Bouteloua* ($P = 0.270$) sites.

	Native		Introduced				
Period (yr)	Control	Harvested	Crested wheatgrass	Russian wildrye	*n*	Mean	SEM
	ANPP ($g \cdot m^{-2}$)						
Stipa–Agropyron–Bouteloua							
1 (1994–1997)	178.5 b[1]	153.8 ab	290.7 c	122.8 a	4	186.4 B[2]	9.1
2 (1998–2001)	178.2 b	138.8 b	137.7 b	87.0 a	4	135.4 A	5.8
3 (2002–2006)	306.1 c	259.0 b	300.8 bc	189.6 a	5	263.9 C	8.8
Mean	220.9 c	183.9 b	243.1 c	133.2 a	13		
CV (%)[3]	51.0	53.3	58.6	50.1	9		
Stipa–Bouteloua							
1 (1995–1998)	66.4 a	75.3 a	265.3 b	93.1 a	4	124.5 A	6.4
2 (1999–2002)	124.3 a	90.7 a	205.1 b	134.4 a	4	138.6 B	6.1
3 (2003–2006)	178.0 b	128.7 a	178.3 b	120.1 a	4	151.3 B	10.5
Mean	122.9 a	98.2 a	216.3 b	115.9 a	12		
CV (%)[3]	41.7	38.1	44.1	36.4	8		

[1]a–d Means followed by a common lowercase letter within row are not different ($P > 0.05$).
[2]A–C means followed by a common uppercase letter within a column are not different ($P > 0.05$).
[3]Coefficient of variation across years of the second and third periods.

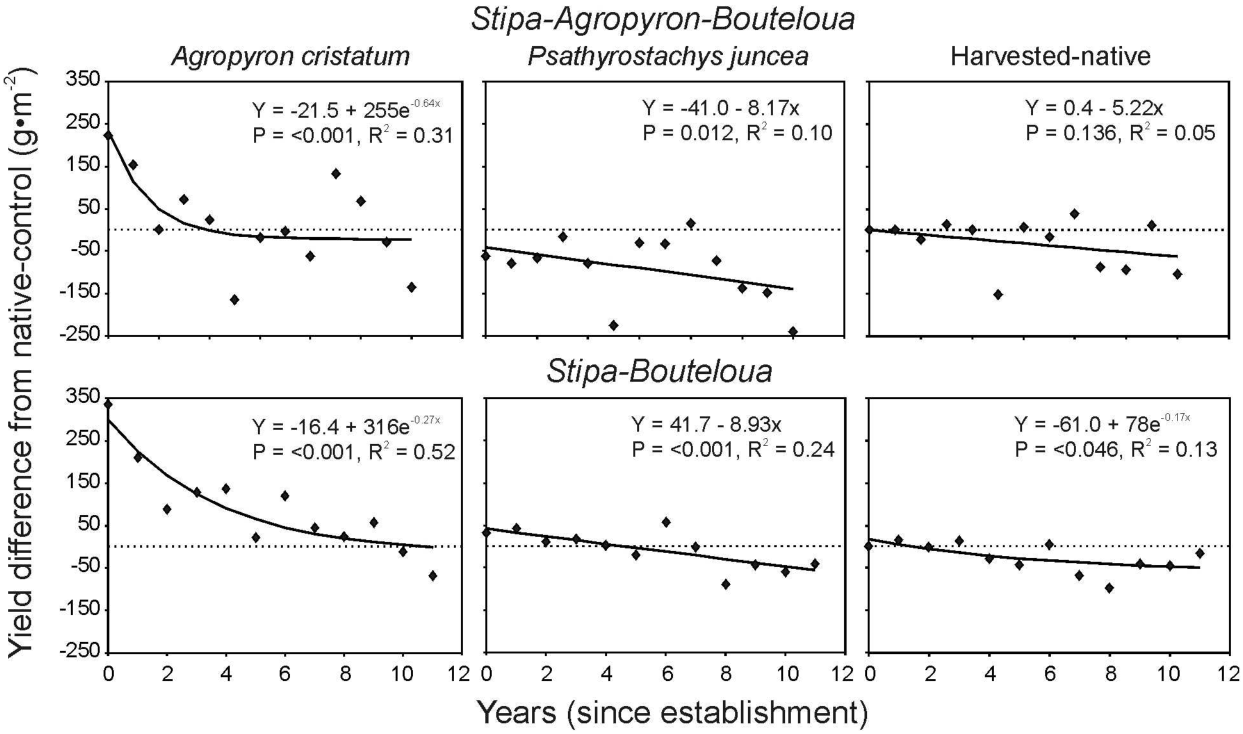

Figure 1. Plots of exponential or linear equations describing the relationship of aboveground net primary production differences between the harvested-native and agronomic treatments and native control (i.e., treatment minus native control) on the *Stipa–Agropyron–Bouteloua* and *Stipa–Bouteloua* sites.

production comparisons of introduced grasses with native communities must consider previous and current grazing management.

The performance of introduced forages is species-specific and a function of their traits. The greater productivity of crested wheatgrass over Russian wildrye was similar to that reported by Smoliak (1968) in a *Stipa–Bouteloua* community and appears related to its ability to establish rapidly and exploit spring moisture through early growth and senescence. Russian wildrye also initiates growth early in spring but it invests a greater amount of energy into the crown (and perhaps the roots) than crested wheatgrass (Willms et al. 2005). Russian wildrye also has been associated with strong competitiveness that excludes infilling from seedlings (Asay and Jensen 1996); however, this phenomenon did not appear to be a factor in our study.

Cultivation Effects

The cultivation effect is defined by the first few years after establishment when the production of the agronomic species, relative to the native control, was the greatest (Fig. 1). This effect is caused by the release of nutrients from killed plants that stimulates microbial activity (Tejada et al. 2008) and mineralization (Erickson and Jensen 2001), and by conserving soil water during the fallow (pre-establishment) period. Although the initial stimulus of cultivation on microbial activity might persist only for a few weeks (Erickson and Jensen 2001), the residual effect can last much longer and contributes to the gradual decline in relative ANPP of the agronomic species. Any effect of a fallow period on available water is short-term and dissipates as the seeded crop becomes established.

Of the agronomic species, crested wheatgrass was most responsive to the cultivation effect but it also exhibited a more rapid decline in ANPP, relative to the native control, from its peak yield (Fig. 1). The greater responsiveness of crested wheatgrass, compared with Russian wildrye, might be explained by its ability to establish more rapidly (Kilcher 1961), thereby exploiting the cultivation-induced available nitrogen more effectively. Therefore, the relative ANPP of crested wheatgrass reached equilibrium earlier than Russian wildrye, which continued to decline in a linear manner until the time the study was terminated (Fig. 1).

Site Effects

The higher productivity of the *Stipa–Agropyron–Bouteloua* site resulted from generally more favorable precipitation (Table 1) and possibly greater N mass than on the *Stipa–Bouteloua* site (Willms et al. 1999). However, compared with the native, the agronomic species performed relatively better in the more xeric *Stipa–Bouteloua* site than in the *Stipa–Agropyron–Bouteloua* site (Table 3). This interaction might be related to the different composition of the native communities, because the agronomic species at each site were identical.

Perhaps the primary difference that dictated the response of the native communities at each site was the relative composition of western wheatgrass and needleandthread. Western wheatgrass is more responsive to soil moisture than needle-and-thread, due to its rhizomatous growth form, and this seems to be reflected in the greater ANPP of the *Stipa–Agropyron–*

Bouteloua site. Smoliak (1965) reported an increase in the basal area of western wheatgrass (but not of needle-and-thread) by spreading straw, which increases soil moisture retention. In the present study the introduced species performed in a similar manner relative to precipitation across the two sites. For example, the average ANPP (Table 3) relative to the growing season precipitation (Table 1) for crested wheatgrass in the *Stipa–Agropyron–Bouteloua* and *Stipa–Bouteloua* sites were 0.85 and 0.87 $g \cdot m^{-2} \cdot mm^{-1}$ precipitation, respectively, whereas for Russian wildrye in the same sites these values were 0.52 and 0.62 $g \cdot m^{-2} \cdot mm^{-1}$ precipitation, respectively. The different responses between sites of the native communities and introduced grasses resulted in 93% and 63% yields of crested wheatgrass and Russian wildrye, respectively, of the native control in the *Stipa–Agropyron–Bouteloua* site and 150% and 96%, respectively, on the *Stipa–Bouteloua* site.

Smoliak et al. (1967) reported relative yields between the native control and crested wheatgrass on a *Stipa–Bouteloua* site that varied from 108% to 1 242% and averaged 372%. These differences are considerably greater than those of the present results, which might be related to differences in their management before and during the study. In the Smoliak et al. (1967) study, both the native and crested wheatgrass were grazed before the trial and then protected from disturbance; in the present study, the native control was ungrazed after the trial began.

ANPP stability, as measured by the CV over years, was expected to be greater in the native treatments than the agronomic species grown as monocultures because of greater species diversity (Tilman 1996; Pfisterer and Schmid 2002). Instead, we observed similar ANPP stability within the agronomic treatments as in the native treatments, which indicates a high level of adaptation by the agronomic species to the climate of the mixed prairie.

What is a Legitimate Control?

The choice of a control to assess the relative performance between native communities and agronomic species will itself introduce unavoidable biases. Our choice was to select a native treatment that was not harvested, with the knowledge that harvesting was likely to reduce ANPP through processes that might be unrelated to those dictating the decline in ANPP of agronomic species. For example, harvesting reduces litter, which conserves soil moisture, and thus enhances rangeland productivity (Willms et al. 1993). Also, native species might be more vulnerable to defoliation. For example, the ANPP of native treatments dominated by needleandthread, western wheatgrass, and blue grama was reduced by about 20% (Table 3), whereas harvesting rough fescue (Willms and Fraser 1992) and northern wheatgrass (*Elymus lanceolatus* subsp. *lanceolatus* [Scribn. & J. G. Sm.] Gould; Kowalenko and Romo 1998) as individual plants within their respective communities reduced subsequent ANPP by about 50%. However, an equivalent treatment in a seeded monoculture of Altai wildrye (*Leymus angustus* [Trin.] Pilger), which had been established for less than 6 yr, did not appear to have any effect on subsequent ANPP (Willms 1991). Therefore, we selected the nonharvested native treatment as the control because it was expected to yield the maximum ANPP and be less affected by extraneous disturbances than was the harvested native. Nevertheless, we recognize that protection from defoliation will itself lead to litter accumulation and a possible distortion in yield potential.

MANAGEMENT IMPLICATIONS

The belief that seeding native grassland to introduced agronomic species would increase forage production was not supported by this study. Crested wheatgrass, probably the most productive of the perennial agronomic species introduced to the mixed prairie, yielded greater ANPP only in the more xeric *Stipa–Bouteloua* site and demonstrated little advantage on the more mesic *Stipa–Agropyron–Bouteloua* site. However, the production risks that might be associated with an introduced monoculture were not evident from the introduced grasses because their CV values were similar to those of the much more complex native communities.

This study did not examine the economic benefits of breaking and seeding native rangeland; such an examination also would have considered the cost of establishment and the risks from soil erosion or loss of production associated with the practice. Crested wheatgrass establishes readily but is primarily useful for spring grazing because it matures early; Russian wildrye establishes slowly and has significant risk of establishment failure.

A great risk of seeding rangeland to a simple species mixture is the potential adverse effect it has on environmental factors such as soil quality or biodiversity. The effect on wildlife species is clearly seen with the loss of native plants. However, associated animal species also become vulnerable if the are not first eliminated by the effect of cultivation. A less obvious impact is the potential loss of soil quality resulting from cultivation and the subsequent replacement of a complex community with a simplified one. As a result of the environmental risks and the uncertain agricultural benefits associated with introduced species, land managers are encouraged to thoroughly consider all implications of such a decision.

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