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M. R. Haferkamp
USDA-Agricultural Research Service

R. K. Heitschmidt
USDA-Agricultural Research Service

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JAPANESE BROME IMPACTS ON WESTERN WHEATGRASS IN NORTHERN GREAT PLAINS RANGELANDS: AN UPDATE

M. R. Haferkamp and **R. K. Heitschmidt**

USDA-Agricultural Research Service
Fort Keogh Livestock and Range Research Laboratory
Miles City, MT 59301
marshall@larrl.ars.usda.gov

ABSTRACT—Japanese brome (*Bromus japonicus* Thunb.) is an annual grass that has invaded thousands of hectares of Northern Great Plains rangelands. We studied the effect of Japanese brome on the current year's increase in biomass in a plant community in the Northern Great Plains dominated by western wheatgrass [*Pascopyrum smithii* Rydb. (Love)]. In our experiment, brome seedlings were either removed or left in place in replicated 1-m^2 plots. Above-ground biomass of western wheatgrass increased (891 to 1,095 kg ha^{-1}) with the removal of Japanese brome. However, total above-ground biomass decreased (1,873 to 1,334 kg ha^{-1}) when brome was reduced in early spring (708 to 12 kg ha^{-1}). Increased biomass of western wheatgrass resulted from increases in the density of tillers and not in the weight of each tiller. Since the effect of removing brome did not vary among the combinations of site and year, similar outcomes can be expected over a wide array of environmental conditions, such as among years with variable April to late-June or mid-July precipitation or stands with varying percents of brome and western wheatgrass. Thus, we conclude that the presence of annual Japanese brome reduces the biomass of important grasses in the Northern Great Plains.

Introduction

Japanese brome (*Bromus japonicus* Thunb.) and downy brome (*B. tectorum* L.), both introduced weedy annual grasses, have invaded thousands of hectares of rangelands throughout the Great Plains (Hitchcock 1950). The time of introduction of Japanese brome into the Northern Great Plains is unclear. However, newspaper reports from Miles City, Montana, suggest downy brome was first noted along the railroads in the late 1930s. Neither Japanese brome nor downy brome appear to have become common in northern mixed-grass prairies before the 1950s. Since then, Japanese brome has invaded un-grazed as well as grazed mixed-grass prairie in the Great Plains (Hewlett et al. 1981; Whisenant 1990; Haferkamp et al. 1993).

And, the invasion of downy brome has converted many acres of sagebrush perennial bunchgrass-dominated communities in western North America into downy brome-dominated communities (Mack 1981).

The management of Northern Great Plains range that is infested with annual bromes is difficult. The grasses avoid drought by remaining in the seed stage, providing a continuing seed supply. In addition, annual production of herbage varies with precipitation and soil nitrogen (Gartner et al. 1986; McLendon and Redente 1991; Haferkamp et al. 1993). The nutritional quality of annual grasses is comparable to perennial grasses at a similar stage, but annual bromes mature more quickly than perennial grasses. Thus, their presence alters the timing of maximal forage production and quality, and so dictates a change in livestock management on infested rangelands (Haferkamp et al. 1994).

Current evidence shows that the biomass of native, cool-season perennials, such as western wheatgrass, increases when annual bromes are removed, by hand pulling (Haferkamp et al. 1997, 1998), burning (Gartner et al. 1978, 1986; Whisenant 1990), or herbicides (Currie et al. 1987). However, the effects of variations in soil, precipitation, and associated species on this relationship need better definition. Our objective in this research was to determine effect of removing Japanese brome seedlings on the current year's net productivity of western wheatgrass-dominated, northern mixed-grass prairie communities with varying soils and environmental conditions. We hypothesized that annual bromes continue to suppress biomass production of western wheatgrass and other plant species growing in northern-mixed-grass prairie communities.

Methods

Study Site. This research was conducted on the Fort Keogh Livestock and Range Research Laboratory (46°22'N 105°5'W) near Miles City, Montana. Regional topography ranges from rolling hills to broken badlands, with small intersecting ephemeral streams flowing into large rivers in broad, nearly level valleys. Indigenous vegetation on the 22,500-ha research area is predominantly the grama grass—needlegrass—wheatgrass (*Bouteloua-Stipa-Pascopyrum*) association (Kuchler 1964). Annual precipitation averages 338 mm, and about 60% of the rainfall is received from April through September (National Oceanic and Atmospheric Administration 1990-1995). Temperature ranges from over 38°C during the summer months to -40°C or less during the winter months. (Fig. 1) The average frost-free period is 150 days (see Haferkamp et al. 1993, 1997, 1998).

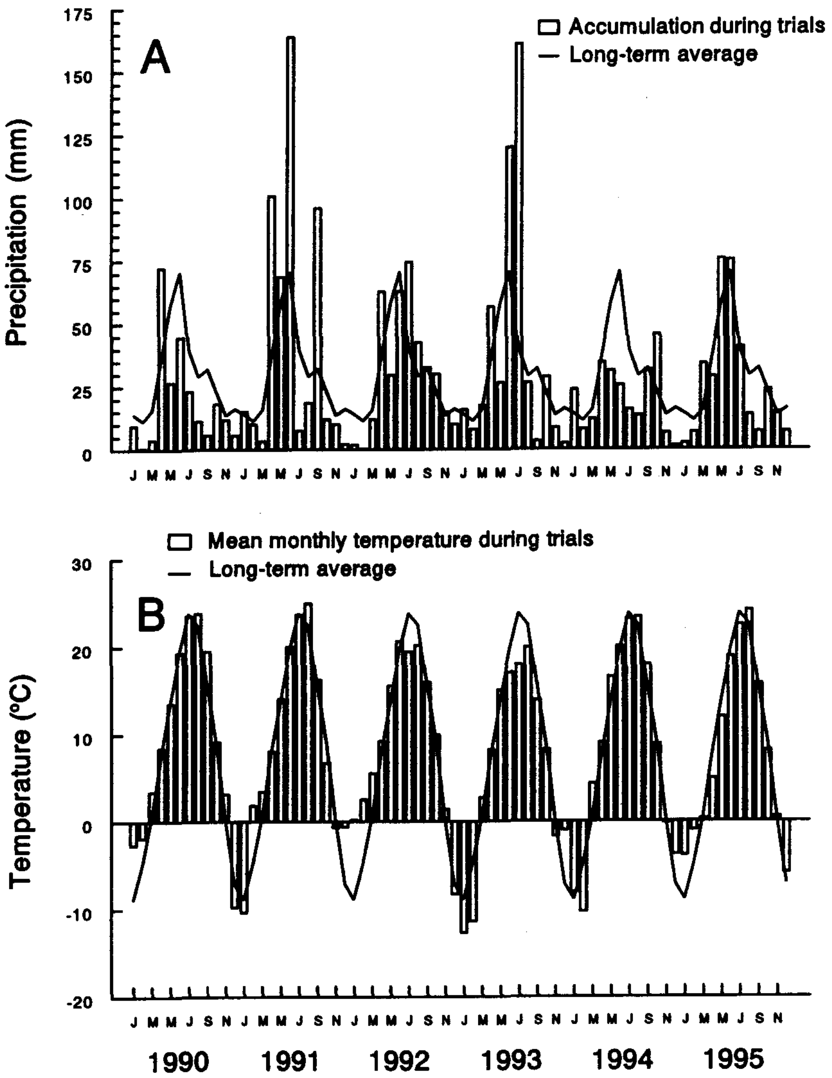

Figure 1. (A) Monthly precipitation (bars) vs. 96-year average (solid line), and (B) average monthly temperature (bar) vs. long-term average (solid line), at the Frank Wiley Airfield, located about 11 km from the study plots (NOAA 1990-1995).

Soils varied among our 6 study sites. They were either a composite of Absher heavy clays (fine, montmorillonitic, Borollic Natrargids) and Gerdrum clay pans (Borollic Natrargids) (1991-1993, 1995 sites) or they were Kobar silty clay loams (fine montmorillonitic, Borollic Camborthid) (1991-1992 sites). Topography is gently sloping (< 2%). The vegetation was dominated by western wheatgrass, blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Griffiths], Sandberg's bluegrass (*Poa secunda* Presl.), sand dropseed [*Sporobolus cryptandrus* (Torr.) Gray], and Japanese brome (Haferkamp et al. 1993, 1997, 1998). For a more complete listing of the vegetation in the area, see in Karl et al. (1999).

Japanese brome seedlings were usually abundant by early March with densities reflecting favorable fall and spring growing conditions. Inflorescences emerged in May, and seeds ripened by mid-June. The plants senesced by late June to mid-July. Vegetative tillers of western wheatgrass began emerging in March and April. Tillers remained in the 4- to 6-leaf stage throughout the measurement period, and few produced inflorescences.

Experimental Design and Treatments. Study sites of about 0.1 ha were selected in spring 1991, 1992, 1993, and 1995, after viewing residual biomass and emerging grass shoots of Japanese brome and western wheatgrass. In 1991 and 1992, two 0.1-ha sites, one for each the clay-clay pan and silty clay loam soils, were studied. In 1993 and 1995 our site was on the clay-clay pan soil. Thus, the experiment was conducted independently six times in four years. Each repeat of the experiment was conducted as a randomized complete block with 10 blocks and two treatments. The treatments were: 1) removal of emerged Japanese brome seedlings 2 or 3 times from mid-April to early June, or 2) control, with the emerged Japanese brome seedlings left undisturbed. Each block represented an internally homogenous mix of Japanese brome and western wheatgrass, plus other annual and perennial grasses and forbs. This paper represents an extension of previously reported results (Haferkamp et al. 1997, 1998). The details of experimental design have been presented in those reports.

Measurements. We determined aboveground biomass, tiller density, and tiller weight of western wheatgrass as well as the biomass of all other plants species after Japanese brome in the control plots matured: early July 1991, late June 1992, and mid-July 1993, 1995. The current year's biomass was clipped at ground level within a circular 0.25-m^2 plot located at the center of each circular 1-m^2 treatment plot. The samples were separated by species and oven-dried for 48 hours at 60°C before weighing. The density of the western wheatgrass tillers was determined by counting the tillers before clipping. The total weight of the western wheatgrass per plot was divided by number of tillers to determine average weight per tiller.

Statistical Analysis. To analyze standing crop and tiller density responses to brome removal, we treated each of the site-year combinations as a replication experiment (N=6) since not all soil subclasses were present each year. The linear analysis of variance model used thus contained the effects of site-year, blocks nested with site-year, treatment, and the interaction of treatment and site-year. A single degree estimate function of the data was used to test the similarity of responses across sites (soil types). All significance tests were conducted using the residual variance, which is equivalent to the interaction of blocks nested within site-year and treatments (i.e., the conventional error for randomized complete block experiments). The Least Significant Difference method ($P \leq 0.05$) protected by a prior F-test ($P \leq 0.05$) was used for comparing means.

Results

Many authors have suggested that annual bromes compete severely with perennial grasses, but few have actually measured competitive response when communities were not affected by fire (Gartner et al. 1978, 1986; Whisenant 1990) or herbicides (Currie et al. 1987; Hewlett et al. 1981). When brome was removed in our study, the biomass of western wheatgrass increased ($F_{1,54} = 15.22$, $P < 0.001$), and the biomass of all vegetation was reduced ($F_{1.54} = 90.68$, $P < 0.001$) (Table 1). The 204 kg ha^{-1} increase in western wheatgrass biomass when brome was removed resulted from an increase in tiller density ($F_{1,54} = 17.35$, $P < 0.001$) not an increase in tiller weight ($F_{1,54} = 0.77$, $P = 0.385$) (Table 2). The biomass of plant species other than western wheatgrass and annual brome, was not affected by brome removal ($F_{1,54} = 0.07$, $P = 0.79$), whereas, biomass of annual Japanese brome was reduced ($F_{1,54} = 362$, $P < 0.001$), but not eliminated (Table 1).

When responses to brome removal were compared between sites that differed in soil type for the 1991-92 period, the results showed that western wheatgrass ($t_{1,54} = -0.68$, $P = 0.50$) and other vegetation ($t_{1,54} = 0.28$, $P = 0.77$) responded equally well to reduction in brome on the clay-clay pan and silty clay loam soil. However, significant differences in response to brome removal were detected for the biomass production of both annual brome ($t_{1,54} = -4.33$, $P < 0.001$) and total vegetation ($t_{1,54} = -3.54$, $P = 0.001$) (Table 3). With brome present, both annual brome and total vegetation were more productive on the silty clay loam than the clay-clay pan soil. When brome

TABLE 1

LEAST SQUARE MEANS AND STANDARD ERRORS (kg ha^{-1}) OF BIOMASS FOR WESTERN WHEATGRASS, JAPANESE BROME, OTHER PLANT SPECIES, WESTERN WHEATGRASS + OTHER PLANT SPECIES, AND TOTAL VEGETATION IN THE BROME EXPERIMENT TREATMENT.[1]

Treatment	Japanese brome	Western wheatgrass	Other species	Western wheatgrass + other spp	Total
Brome present	708^{a}	891^{b}	274^{a}	$1,165^{b}$	$1,783^{a}$
Brome removed	12^{b}	$1,095^{a}$	267^{a}	$1,361^{a}$	$1,374^{b}$
Standard error	25.85	37.00	20.57	36.33	37.08

[1]Means for treatments for each species group followed by similar letters are not significantly different ($P \geq 0.05$).

was removed, no differences were detected in production between the two soils in 1991 or 1992.

Differences in precipitation patterns among years and in soil textures among sites, and thus soil water dynamics, resulted in six different year-soil environmental combinations. The biomass of annual brome ($P_{5,54} = 6.43$, $F < 0.001$) and total vegetation ($P_{5,54} = 2.69$, $F = 0.031$) was consistently reduced by the brome removal treatment with one exception; the exception was biomass of total vegetation on the clay-clay pan soil in 1992 (Table 3). Most of the variation in the biomass of annual brome without brome removal and the biomass of total vegetation occurred among years in both treatments (Table 3). The biomass response of other plant species excluding western wheatgrass, to brome removal also varied among the site-year combinations ($P_{5,54} = 3.02$, $F = 0.018$) (Table 3). However, biomass response of western wheatgrass ($P_{5,54} = 0.41$, $F = 0.84$) and of western wheatgrass + other vegetation ($P_{5,54} = 0.85$, $F = 0.52$) to brome removal treatments was not affected by the variation among site-year combinations.

TABLE 2

LEAST-MEANS FOR WESTERN WHEATGRASS TILLER DENSITY AND TILLER WEIGHT IN BROME EXPERIMENT TREATMENTS AND SITE-YEAR COMBINATIONS.[1]

Treatment/site-year	Tiller density (Number m^{-2})	Tiller weight (grams)
Treatments		
Brome present	560^{b}	0.178^{a}
Brome removed	690^{a}	0.185^{a}
Standard error	22.06	0.006
Site-Year Combinations		
Clay-clay pan site		
1991	529^{d}	0.213^{b}
1992	776^{ab}	0.100^{d}
1993	609^{cd}	0.206^{b}
1995	845^{a}	0.144^{c}
Silty clay loam site		
1991	305^{e}	0.288^{a}
1992	686^{bc}	0.139^{c}
Standard error	38.20	0.011

[1] Means for treatments or site-year combinations followed by similar letters for tiller density or tiller weight are not significantly different ($P \geq 0.05$).

Averaged across brome removal treatments, the biomass response by western wheatgrass was greatest on the clay-clay pan soil in 1991, 1993, and 1995 ($P_{5,54} = 8.40$, $F < 0.001$) (Table 4). The biomass response of western wheatgrass + other plant species was greatest on the clay-clay pan soil in 1993 and 1995 ($P_{5,54} = 38.00$, $F < 0.001$).

Western wheatgrass tiller densities were greater on the clay-clay pan than silty clay loam soil in both 1991 and 1992 ($P_{5,54} = 25.59$, $F < 0.001$) (Table 2). Tiller weights, however, were greater on the clay-clay pan than silty-clay loam soil in 1991, but similar on the two soils in 1992 ($P_{5,54} = 37.26$, $F < 0.001$) (Table 2).

TABLE 3

LEAST-SQUARE MEANS (kg ha^{-1}) AND STANDARD ERRORS (S.E.) FOR THE TREATMENT BY SITE-YEAR COMBINATION INTERACTION IN BIOMASS RESPONSE TO BROME REMOVAL FOR: OTHER PLANT SPECIES, JAPANESE BROME, AND TOTAL VEGETATION.[1]

Species/	Clay-clay pan				Silty clay loam	
Treatment	1991	1992	1993	1995	1991	1992
Other species (S.E.=50.38)						
Brome present	72^{Ca}	50^{Ca}	822^{Aa}	264^{Ba}	326^{Bb}	111^{Ca}
Brome reduced	112^{Ca}	47^{Ca}	634^{Ab}	292^{Ba}	500^{Aa}	14^{Ca}
Japanese brome (S.E.=63.31)						
Brome present	508^{Ca}	647^{Ca}	511^{Ca}	633^{Ca}	$1,110^{Aa}$	839^{Ba}
Brome reduced	6^{Ab}	T^{Ab2}	3^{Ab}	40^{Ab}	25^{Ab}	T^{Ab}
Total vegetation (S.E.=50.38)						
Brome present	$1,586^{DEa}$	$1,259^{Ea}$	$2,361^{Aa}$	$2,028^{BCa}$	$2,204^{ABa}$	$1,801^{CDa}$
Brome reduced	$1,288^{Cb}$	946^{Da}	$1,939^{Ab}$	$1,588^{Bb}$	$1,450^{BCb}$	$1,032^{Db}$

[1] Means for site-year combinations with similar uppercase letters are not significantly different within each species group-treatment combination ($P \geq 0.05$). Means for treatments within each species group followed by the same superscript lowercase letters are not significantly different within each site-year combination.

Discussion

The increase in biomass of western wheatgrass in northern mixed-grass prairie communities in response to manual removal of brome agrees with findings of others who burned (Gartner et al. 1978, 1986) or sprayed with herbicide (Hewlett et al. 1981) to remove brome. Similar results, showing an increase in biomass caused by an increase in tiller density, have also been reported for other grasses (Briske and Butler 1989). The bulk of the in each

TABLE 4

LEAST-SQUARE MEANS (kg ha^{-1}) AND STANDARD ERRORS FOR BIOMASS BY SITE-YEAR COMBINATION OF: WESTERN WHEATGRASS, JAPANESE BROME, OTHER PLANT SPECIES, WESTERN WHEATGRASS + OTHER PLANT SPECIES, AND TOTAL VEGETATION.[1]

Site-year	Western wheatgrass	Japanese brome	Other species	Western wheatgrass + other species	Total
Clay-clay pan site					
1991	1,089^{ab}	257^{c}	92^{d}	1,181^{c}	1,437^{c}
1992	730^{d}	324^{bc}	49^{d}	779^{e}	1,103^{d}
1993	1,165^{a}	257^{c}	728^{a}	1,893^{a}	2,150^{a}
1995	1,192^{a}	337^{bc}	229^{c}	1,471^{b}	1,808^{b}
Silty clay loam site					
1991	846^{cd}	568^{a}	413^{b}	1,259^{c}	1,827^{b}
1992	934^{bc}	420^{b}	62^{d}	996^{d}	1,416^{c}
Standard error	64.09	44.76	35.63	62.93	64.22

[1] Means for each site year combination for each species group followed by similar letters are not significantly different ($P \geq 0.05$).

plot was produced by western wheatgrass, but each plot also contained other grasses and forbs. So, the increase in biomass of western wheatgrass might have been larger if it were grown with only Japanese brome. Resources released by removing brome were probably shared among all of the actively growing plants (Parrish and Bazzaz 1976; Goldberg and Werner 1983). We do not know how much of the potential increase in resources was used by plant species other than western wheatgrass.

The increase in biomass of western wheatgrass did not totally compensate for biomass lost by brome removal, and biomass of other plant species was not generally affected by brome removal. Thus, total biomass decreased. This decrease in total aboveground biomass in response to brome removal is also consistent with the results of other studies using burning (Gartner et al.

1978, 1986) or herbicides (Hewlett et al. 1981) to remove brome. Hewlett et al. (1981) speculated that reduction in total biomass may have resulted from the adverse effect of herbicide on perennials. Herbicide, however, was not a factor in our studies. Alternately, root growth into soil gaps may allow plants to occupy greater soil volumes and more nutrient rich microsites in soils (Eissenstat and Caldwell 1989), but greater resource acquisition with increased root volume may not be apparent immediately. For example, for western wheatgrass we do not know how thoroughly or rapidly the rhizomes and roots grew into soil gaps left vacant of annual brome, or whether any extra growth would be apparent above ground in the growing season when brome was removed. Mueller (1941) reported that new rhizomes of western wheatgrass form concurrently with the shoots, if there were adequate resources (e.g., carbohydrates, water, etc.) available for growth. So aboveground response to below-ground expansion would be expected.

Since new sites were chosen each year, we expected and found annual variation in total biomass (1,260 to 2,538 kg ha^{-1}) and varying contributions to total biomass by annual bromes (22 to 51%), western wheatgrass (35 to 63%), and other grass and forb species (4 to 35%). Soils varied among years, as well as, amounts and distribution of precipitation from September through November (35 to 118 mm) and April through late June or mid-July (101 to 382 mm). However, our major interest was in how biomass production changed with brome removal under varied site-year environmental combinations. In general, biomass response of western wheatgrass, or western wheatgrass + other vegetation, to brome removal was consistent among years, as demonstrated by the lack of significance in the interaction between site-year combination and brome treatment. Although this interaction was significant for total biomass, for Japanese brome and for other plant species, the interactions accounted for less than 7% of the total variation.

Suppression of annual brome is a continuing challenge. Hand pulling in early spring is not a realistic way to suppress annual bromes on large acreages. Suppression of brome requires environmental management (burning, herbicide, grazing) to reduce annual brome seedbank. Adequate residual seed to allow an increase in brome abundance may be available even after 2 years of suppression. Several studies have shown increases in forage yields of perennial grasses with suppression of annual bromes with herbicides and burning. Whisenant (1990) suggested greater reduction of annual bromes from burning can be expected when precipitation is below normal in the year following the burning. This response is a result of reduction in litter accumulation, which reduces recruitment, seed production, and seed banks.

Some chemicals that have been used to control annual bromes, e.g., atrazine, are no longer labeled for use on rangelands, but some herbicides labeled for downy brome control on rangelands are available (Dewy et al. 1998).

Conclusions

The increase in western wheatgrass tiller density with brome removal suggests brome removal may have long-term impact by allowing western wheatgrass to become more dominant in the community. The non-significant interaction between site-year combination and brome removal treatment in explaining western wheatgrass yield response suggests these results can be expected over a wide array of environmental conditions and vegetation mixes, containing varying amounts of annual brome, western wheatgrass, and other grass and forb species.

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