THE USE OF WEED TECHNOLOGY IN PALOUSE PRAIRIE REMNANTS FOR

MANAGEMENT AND RESTORATION

By

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A thesis submitted in partial fulfillment of

the requirements for the degree of

MASTER OF SCIENCE IN CROP SCIENCE

WASHINGTON STATE UNIVERSITY

Department of Crop and Soil Sciences

AUGUST 2010

To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of RANDALL ELLIOTT

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ACKNOWLEDGEMENTS

I would like to thank my committee for their support and guidance over the years. A special thanks to Ian Burke, my chair, for giving me the opportunity, teaching me the tools, and assiduously editing. I would also like to thank Dennis Pittmann for his help, friendship and always cheerful attitude (and letting me drive the tractor sometimes). To my fellow graduate students for suffering alongside me in the field and classroom alike – best of luck in your futures. To Nick Boydston and the rest of the lab staff for help with sampling and processing, I couldn't have gotten it all done without you and your hard work. And of course to my friends and family for their understanding, support, and love during the last few years, through the good, bad, and crazy; and for the endless jokes about weed science.

THE USE OF WEED TECHNOLOGY IN PALOUSE PRAIRIE REMNANTS FOR

MANAGEMENT AND RESTORATION

Abstract

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August 2010

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Two studies were conducted to enhance management and restoration of prairie

grasslands. First, utilizing a replacement series, interactions were compared between two prairie

junegrass *Koeleria macrantha* (Ledeb.) Schult. biotypes from the Rocky Mountains (RM) and

Eastern Washington (EW). Replacement series diagrams indicate RM height, basal area, and

biomass was not affected when grown with EW, but EW growth was reduced when grown with

RM. The EW biotype was reduced to 85%, 86%, and 71% of monoculture yield for height, basal

area, and biomass, respectively. Only reductions in height and biomass were significant.

Average relative yield (RY) values trend below the line $RY_{RM} = RY_{EW}$ and indicate RM had a

competitive advantage across all yield metrics. Relative crowding coefficient indicated RM had

a greater competitive ability than EW for height, 1.125 to 0.889; basal area, 1.369 to 0.730; and

biomass, 1.51 to 0.660, respectively.

The second study evaluated effects of registered and non-registered herbicides to control

grassy weeds for use in degraded Palouse prairie remnants. The herbicide treatments applied

were chlorsulfuron at 30 g/ha, diclofop at 1120 g/ha, imazapic at 140 g/ha plus glyphosate at 190

g/ha, mesosulfuron at 190 g/ha, metribuzin at 600 g/ha, propoxycarbazone at 40 g/ha pyroxsulam

at 230 g/ha, or sulfosulfuron at 50 g /ha, all applied with a nonionic surfactant at 0.5% v/v.. A nontreated control was included for comparison. Cover and richness data were recorded by species and divided into functional groups based on native status. Pyroxsulam, diclofop, and propoxycarbazone treatments had the greatest increase in species richness for total native plants over the nontreated, 5.0, 4.4, and 4.4 respectively ($P > 0.0012$). Pyroxsulam, sulfosulfuron, and imazapic plus glyphosate treatments reduced alien grass richness to 0.9, 0.8, and 0.8, respectively, contrasted with 1.8 for nontreated areas ($P > 0.0032$). Total native plant cover and native forbs cover increased most over nontreated plots with the application of pyroxsulam, 97% ($P > 0.0363$) and 88% ($P > 0.0235$), respectively. Imazapic plus glyphosate and sulfosulfuron significantly reduced alien grass cover over the nontreated 73% and 69% respectively, and were similar to pyroxsulam, chlorsulfuron, and diclofop ($P < 0.0307$).

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Dedication

To the memory of my mother and my grandmother.

Introduction

Succession within a plant community is a naturally occurring phenomenon in which species interactions, diversity, and associations change as a response to seral initiation as the community progresses towards a climax structure (Clements 1916, Walker and Smith 1997). Seral changes are initiated following natural occurring disturbance events that tend to be cyclical within the community. Often a community has a long life history of these disturbances evident within the climax community (Clements 1916). Prairie community succession and stability has been severely altered by anthropogenic activities such as farming and ranching (Noss et al 1995; Tisdale 1961; Woods 1997). Many prairie systems are no longer at a sufficient size or lack the ability as a prairie habitat to maintain a functional system and successionally recover following a disturbance (Clements 1916; Tisdale 1961; Walker and Smith 1997). Furthermore nonnative species invade and inhabit prairies systems and replace or alter the prairie plant community structure (Walker and Smith 1997; Westoby et al 1989). Often nonnative species were also introduced by human-related activities. The introduction of alien species changes the way succession functions and differs from traditional succession in that it involves species that are not components of the native plant community and occupy niches that displaces native species (Keeley 2006). Often the degradation of prairie sites and function and the introduction of and subsequent invasion of nonnative species coincide to create an undesired effect upon the landscape. In order to establish new prairie or to preserve what already exists it is important to understand the processes that drive succession and the impact that non-native species have - by doing so we can develop management plans that will remove invasive species and facilitate a return to pre-invasion ecosystem functionality.

The Palouse prairie originally encompassed a region in the Pacific Northwest extending east from the Cascade Mountains of Washington and Oregon into Idaho, east into Montana, south into Utah, and north into British Columbia (Lichthardt and Moseley 1997). For the purpose of this introduction, however, it will refer to the prairie grassland system within the geographical region of the Palouse in southeastern Washington and neighboring parts of northern Idaho. The Palouse region is defined physically by rolling hills of wind deposited loess soils over a basalt rock base layer (Lichthardt and Moseley 1997; Sánchez-de León and Johnson-Maynard 2009). Due to agricultural practices that converted grasslands to crop production more than 100 years ago (Daubenmire 1940; Tisdale 1961) the Palouse prairie in this region is rare and is limited to small remnant patches (Aller, et al. 1981; Lichthardt and Moseley 1997). Less than 0.1% of the Palouse remains comparatively unaltered and it is considered the most endangered ecosystem in the United States (Noss et al. 1995). Disturbances near to and in the remnants have led to an increase in alien grasses, mainly annual brome species, *Bromus spp.* (Lichthardt and Moseley 1997).

Relatively few herbicides are registered for use in non-crop areas such as native prairie remnants. Even fewer have tolerance data on native grasses and forbs. Many of the products that control of downy brome and other invasive grasses could potentially harm more desirable species. Of the limited number of herbicides registered for use in non-crop and rangeland areas a few, such as chlorsulfuron, imazapic, and sulfosulfuron, control downy brome, but variable control has also been reported and herbicide resistance can be an issue (Butler et al. 2008; Butler and Crockett 2008; Ball and Mallory-Smith 2000; Mallory-Smith et al. 1999; Park and Mallory-Smith 2004). In a study conducted on central Oregon rangeland a November application of imazapic at 0.21 kg ae/ha plus glyphosate at 0.42 kg ae/ha achieved 100% control of downy

brome (*Bromus tectorum* L.) and medusahead (*Taeniatherum caput-medusae* (L.) Nevski) (Butler et al. 2008). A similar study in Oregon found that applications of sulfosulfuron at 43 g ai/ha controlled downy brome from 45 to 68% depending on location (Butler and Crockett 2008). A study on the effects of sulfosulfuron applied at 70 g/ha on downy brome and other grasses also found a reduction in photosynthetic activity of ranging from 76 to 100% after application (Monaco and Creech 2004). The registration of imazapic plus glyphosate (Anonymous 2008) may be an alternative that could yield similar control on downy brome and other undesired annual grasses.

The identification of new or alternative chemical control inputs for use in prairie systems need to be identified to expand the limited management tools used to control invasive species. Little is known about the effect of herbicides on pre agricultural Palouse Prairie species. Invasive species removal could initiate a seral change allowing for recovery of degraded site that is returning the native species to functional ecosystem. Research to evaluate the efficacy of currently registered and non-registered herbicides for the control of invasive grass weeds such as downy brome and ventenata in Palouse Prairie is needed. As effects on non-target vegetation are highly undesirable, the effect on and response of the desirable native plant community was also evaluated. Because the native remnants are rare and potentially highly susceptible to further alien plant invasion, management options that are relatively low impact in application and effect on native species while at the same time show high efficacy on alien species are needed.

More traditional theories of community ecology hypothesize that removing the disturbance that caused an invasion will cause the system to return to a pre-invasion state through succession (Clements 1916; Woods 1997). There are examples to support this hypothesis (Egler 1942) and many more that do not (Cuddihy and Stone 1990; Wilson 1989). In

many cases once one invasive species is removed from an area, a different invasive species emerges as dominant before the native community can reestablish (Walker and Smith 1997). The invasion may have caused a change to the system that inhibits native species establishment, such as a change in soil structure (Brown et al 2008), disturbance regime (D' Antonio an Vitousek 1992; Hughes et al. 1991; Mack 1986; Young and Evans 1978), or nutrient availability (Lodge et al. 1994) that a native species cannot grow or compete in. An invasion may cause a loss of native species that would be needed to fill the niche occupied by the alien species (Walker and Smith 1997).

Following the removal of undesired species, a management strategy that is often employed is to plant back more desirable species to increase diversity and fill the newly opened niches. Selecting plant material well suited for this purpose is important to its success (Watkins 2009). Often species have ecotypes or biotypes that are more suited to specific regions or growing conditions (Keeler 1992). Knowledge of the intrinsic characteristics of such biotypes or ecotypes allows restoration workers to choose plant material better suited to specific niches.

Prairie junegrass, *Koeleria macrantha* (Ledeb.) Schultes, is an example of such a species used in restoration and may be useful in for revitalizing Palouse Prairie. Prairie junegrass is a small statured perennial bunchgrass with a compact tuft of fine leaves and slender culms (Dixon 2000). It has a wide degree of plant phenotypic and morphological variability depending on habitat, geography, and ploidy level (Dixon 2000; Robertson 1974). *Koeleria macrantha*, formally known as *Koeleria cristata*, is widely spread and native in many grassland ecosystems. It is found in the temperate areas of most of North America, Europe, Asia, and Africa (Tsvelev 1983). Although it is not often dominant, prairie junegrass is important as an intermediate seral stage species in grasslands. It has become well adapted to many soil types, environmental

conditions, and geographic locations. Important attributes include tolerance to: drought, alkaline soils, sandy soils, and salinity (Watkins 2009; Dixon and Todd 2001). Prairie junegrass is found on the coast in Britain at sea level to high mountain areas in Nepal at 4400 m in elevation. Biotypes are adapted to temperature extremes of 39° C in Spain to -50° C in Siberia (Dixon 2000). Because of the ability of this species to live in such a large variety of habitats and conditions there is considerable interest in germplasm and cultivar development for use in various turf grass programs for areas of low input. Watkins found that, in terms of seed production, genotypes of prairie junegrass native to North America outperformed varieties from southwest Asia (Watkins 2009).

Biotypes of prairie junegrass have variable ploidy levels. Prairie junegrass has a base chromosome level of 7, and is most commonly found as a diploid (2n=14) or a tetraploid (2n=28). There are also reports of biotypes where 2n=42, 2n=56, and 2n=84 (Rolly and Bajon 1988) and 2n=42 and 2n=70 (Dixon 2000). Populations of a specific ploidy level have been associated with geographic and habitat conditions. Higher ploidy levels are often found in harsher environments (Robertson 1974; Stebbins and Love 1941). In a study of sixteen prairie junegrass populations from North America, Robertson (1974) found that there were only four tetraploid populations (2n=28), all from sagebrush grasslands, which contrasted with the diploid population that occurred in areas with more favorable moisture regimes. This is most likely due to the increased competitive ability of diploids over polyploids on sites with more favorable growing conditions such as increased and timelier rainfall, nutrient availability, and lack of disturbance, as suggested by Stebbins (1971). The polyploid biotypes are left to fill niches in less favorable ecotypes that lay outside the range that the diploids have adapted to (Keeler 1992).

Outline

This thesis is a compilation of an introduction and two journal articles in lieu of chapters. The

articles were formatted for submission to *Weed Technology*. Additional authors were involved

with regards to experimental design, statistical analysis, and editing.

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Competition Study of Two Prairie Junegrass Biotypes of Differing Ploidy Levels

Randall E. Stevens, Ian C. Burke, and Mark E. Stannard[1]

Abstract

Prairie junegrass, *Koeleria macrantha* (Ledeb.) Schult., is a perennial bunchgrass native to temperate environments of Asia, Europe, North America and Africa (Tsvelev 1983). Utilizing a replacement series design, the competitive interaction of two biotypes from different regions of North America, the Rocky Mountain (RM) and Eastern Washington (EW) biotype planted at ratios of RM:EW, of 8:0, 7:1, 6:2, 5:3, 4:4, 3:5, 2:6, 1:7, and 0:8, was studied. Replacement series diagrams indicate that RM height, basal bunch area, and dry biomass was not affected when grown with EW, but EW growth was reduced when grown in competition with RM. There was no significant loss for RM yield grown in competition in comparison with expected yield in monoculture for height, bunch area, or dry biomass ($P = 0.1291$, 0.4145, and 0.9000, respectively). The EW biotype was reduced to 85.2%, 86.1%, and 71.4% of the yield in monoculture for height, basal bunch area, and biomass, respectively. Only the reductions in height and biomass were significant ($P < 0.0001$ and $P = 0.0003$ respectively). Bunch area was highly variable and did not differ among the two biotypes. The average values for relative yield

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(RY) trend below the line $RY_{RM} = RY_{EW}$ and indicate that RM had a competitive advantage over EW across all yield metrics: height, bunch area, and biomass. The relative yield total (RYT) results for height and biomass had a different y-intercept compared to expected yield ($P = 0.0613$ and $P = 0.0880$ respectively) indicating a competitive effect between the two biotypes. Relative crowding coefficient indicated that RM had a greater competitive ability than EW for height, 1.125 to 0.889; basal area, 1.369 to 0.730; and biomass, 1.51 to 0.660, respectively.

Nomenclature: Prairie junegrass, *Koeleria macrantha* (Ledeb.) Schult.

Keywords: Replacement series, ploidy level, relative yield, relative yield total, relative crowding coefficient.

Introduction

Prairie junegrass (*Koeleria macrantha*) is a small statured perennial bunchgrass with compact tuft of fine leaves and slender culms (Dixon 2000). It has a wide degree of plant phenotypic and morphological variability depending on habitat, geography, and ploidy level (Dixon 2000; Robertson 1974). Formally known as *Koeleria cristata*, prairie junegrass is widely occurring in many grassland ecosystems. It is found in the temperate areas of most of North America, Europe, Asia, and Africa (Tsvelev 1983). Although it is not often dominant, prairie junegrass is important as an intermediate seral stage species in grass ecosystems. It is well adapted to many soil types, environmental conditions, and geographic locations. Important attributes include tolerance to drought, alkaline soils, sandy soils, and salinity (Watkins 2009; Dixon and Todd 2001). Biotypes also have a differential response to varying rates of soil calcium and magnesium (Dixon and Todd 2001). Prairie junegrass is found on the coast in Britain at sea level to high mountain areas in Nepal at 4,400 m in elevation. Biotypes are adapted to temperature extremes of 39 C in Spain to -50 C in Siberia (Dixon 2000). Because of the ability of this species to live in such a large variety of habitats and conditions there is considerable interest in germplasm and cultivar development for use in various turf grass programs for areas of low input. Watkins found that, in terms of seed production, genotypes of prairie junegrass native to North America outperformed varieties from southwest Asia (Watkins 2009).

Biotypes of prairie junegrass have different ploidy levels. Prairie junegrass has a base chromosome level of 7, and is most commonly found as a diploid (2n=14) or a tetraploid (2n=28). There are also reports of biotypes where 2n=42, 2n=56, and 2n=84 (Rolly and Bajon 1988) and 2n=42 and 2n=70 (Dixon 2000). Populations of a specific ploidy level have been

associated with geographic and habitat conditions. Higher ploidy levels are often found in harsher, more stressful environments (Robertson 1974; Stebbins and Love 1941). In a study of sixteen prairie junegrass populations from North America, Robertson (1974) found that there were four tetraploid populations (2n=28), all from sagebrush grasslands, which contrasted with diploid population that occurred in areas with levels of rainfall and available moisture. As suggested by Stebbins (1971), this is most likely due to the competitive ability of diploids being greater than polyploids on sites with less stressful growing conditions such as increased and timelier rainfall, nutrient availability, and lack of disturbance. The polyploid biotypes are left to fill niches in ecotypes that lay outside the adaptive range of the diploids (Keeler 1992).

The objective of this study was to investigate differences in growth of prairie junegrass biotypes from two geographically separated populations with potential adaptive differences under competitive conditions. This could be used to identify appropriate uses of prairie junegrass biotypes in turf programs or as a restoration/revegetation (Woosaree et al. 2004) species based on genomic factors.

Materials and Methods

The experiment was performed in a glasshouse located on the Washington State University Pullman campus and repeated in space from February 2008 to May 2009. All seeds where obtained from the NRCS Pullman Plant Materials Center (PMC). The original sources of the seeds were from eastern Washington at the Rose Creek Nature Preserve near Albion, WA (46° 49'31" N, 117° 12'27"W), and from Colorado from the Rocky Mountain National Park (40° 22'19" N, 105° 31'41"W), referred to throughout by biotype as EW and RM, respectively.

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Seeds were started in seedling trays[1]. When seedlings were established in the trays, approximately 6 weeks after planting, plugs of each biotype were transplanted into 0.022 m^3 pots. Plugs were elected by appearance for uniform height (~5cm), root establishment, and leaf number (3-4). The pots were filled with a commercial potting media[2] and clean sand mixed in a ratio of 4:1 by volume, respectively. Natural light was supplemented in the glasshouse by overhead sodium vapor lighting at 980 µmol/m^2/s creating a total photoperiod of 14 hours each day for the duration of the experiments. Temperature in the glasshouse was maintained at 32/25 C (± 3 C) day/night. Pots were rotated in the glasshouse approximately every 7 days to minimize any glasshouse bench temperature and lighting gradient effects.

Each pot, which constituted a replicate, contained 8 plants. Treatments were ratios of EW:RM used and were: 8:0, 7:1, 6:2, 5:3, 4:4, 3:5, 2:6, 1:7, and 0:8 respectively. Each of the 9 treatments was replicated four times in each experiment. The plants were marked with small plastic stakes color coded according to biotype. Plants were subirrigated when soil began to appear dry, but before any plant wilting occurred. Each pot was fertilized 14 d after planting (DAP) with 10 g of a slow release fertilizer[3]. At 370 DAP height and bunch diameter at ground level was taken for each plant. Plants were then cut off at ground level, individually bagged, and placed in a drying oven at 43 C for 5 days. Upon removal from the oven dry biomass was weighed. Bunch diameter was used to determine basal area.

Data were tested for homogeneity of variance by plotting residuals. To recognize treatment structure in the factorial treatment arrangement, ANOVA was conducted using the MIXED procedure in SAS[4] with sums of squares partitioned to reflect trial and treatment effects, both considered fixed effects. Main effects and block interactions were tested by the appropriate

mean square associated with the fixed variables (McIntosh 1983). ANOVA indicated no

significant trial main effects, so data were pooled over trials for analysis.

The relative yield, RY; relative yield total, RYT; and relative crowding coefficient, RCC,

were calculated as described by de Wit as presented by Harper (1977), Pantone (1995), and

Williams and McCarthy (2001). The RY at each ratio is calculated as:

$$RY_{RM} = y_{RM}/(p_{RM}* m_{RM}) \tag{1}$$

for the RM biotype and

$$RY_{EW} = y_{EW}/(p_{EW}* m_{EW}) \tag{2}$$

for the EW biotype. For the appropriate biotype 'y' is the yield at the proportion 'p' of the

biotype in the mixture, and 'm' is the yield of the respective biotype in monoculture. Yield

parameters include dry aboveground biomass, plant height, and basal area of the grass bunch.

RY values of 1.0 indicate that intra- and interspecific competition is equal for that biotype.

Values > 1.0 indicate that the biotype is more competitive with the other biotype than with itself.

An RY value < 1.0 indicates that interspecific competition is greater and the presence of the

other species is causing a reduction in biomass. This is graphically represented when RY_{RM}

values (x-axis) are plotted against RY_{EW} values (y-axis). Values that lay above a theoretical line

of $RY_{RM} = RY_{EW}$ indicate where EW is more competitive and values below where RM is more

competitive (Williams and McCarthy 2001).

Relative yield total (RYT) acts as an indicator of the type of relationship that the biotypes

have with each other and the limiting factors in their environment. The RYT is calculated using

the values derived from the RY calculations, and RYT is visually assessed like RY, were mean

RM yield is on the x-axis and EW yield is on the y-axis. The points are the mean yield pairs for

each planting ratio level. A line is drawn between the yields in monoculture representing

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expected yield for equal contribution under no or equal competitive effect. Likewise, points that fall on the expected yield line show when there is no competitive effect, where RYT = 1. Points above the line indicate RYT > 1, suggesting that the species have niche differentiation or a symbiotic relationship. Points below the line show, where RYT < 1, indicate that there is competition occurring and that one species is less competitive, or that both species are antagonized by each other (Harper 1977).

The relative crowding coefficient (RCC) is a measurement of the effect or pressure of one species on another in competition. It is a relative comparison of the yield at an equal proportion of planting, in this case 4:4. The equation used to calculate RCC of EW with respect to RM is as follows:

$$RCC_{EW:RM} = (x_{EW} / x_{RM}) / (m_{EW} / m_{RM}) \qquad [3]$$

where 'x' is the mean yield of the respective biotype in mixture and 'm' is the mean yield of the respective biotype in monoculture. Values need only be calculated for one biotype in respect to the other biotype. Values of 1.0 indicate that the species or biotypes do as well in competition as in monoculture. This indicates direct and equal competition for the same resources or in the same niche. Values greater than 1.0 indicate, in this instance, that EW is more competitive and that it is producing more biomass in competition than monoculture on a per plant basis. Values less than 1.0 would indicate that EW is not as interspecifically competitive with RM as it is intraspecifically competitive with itself.

Results and Discussion

In monoculture RM accumulated more biomass and had a lower average height, but there was no difference in grass plug area compared to EW (Table 1). Although the grass bunches

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were not different in area, RM was slightly larger and observationally had a higher leaf/tiller density. This accounted for the higher biomass even though the plants were shorter in stature.

Replacement series diagrams were constructed in accordance with Harper (1977). The yield data were plotted on the y-axis against the biotype ratio along the x-axis. Straight lines indicate no interaction or competition, or a niche differentiation between the biotypes in mixture, or that the biotypes exert the same amount of pressure intraspecifically as interspecifically. Lines that are curved indicate competition between the species for resources. The diagrams for height, basal area, and for mass (Figure 1) indicate that interspecific competition occurred. A straight line for RM and a concave line shape for EW on all three plots suggested that RM was not affected when planted with EW, but that EW growth was negatively affected when grown with RM. There was no significant loss for RM yield grown in competition when compared to expected yield in monoculture for height, basal area, or dry biomass ($P = 0.1291, 0.4145$, and 0.9000 respectively). The overall total yield of EW biotype was reduced to 85.2%, 86.1%, and 71.4% of the monoculture yield for height, basal area, and biomass, respectively. Only the reductions in height and biomass were significant ($P < 0.0001$ and $P = 0.0003$ respectively). Basal area was highly variable and did not differ among the two biotypes (Figure 1).

Values obtained for RY, RYT, and RCC are similar and correlate with the replacement series results. The average values for RY trend below the line $RY_{RM} = RY_{EW}$ and indicate that RM had a competitive advantage over EW across all yield metrics; height, bunch area, and biomass (Figure 2). Where the average values were in the area below $RY_{EW} = 1.0$ and above an area where $RY_{RM} = 1.0$, it indicated that RM not only had the competitive advantage but that RM suppressed the yield of EW as observed for bunch area and for biomass (Figure 2).

The relative yield total results were calculated across all yield parameters to determine if a competitive interaction occurred between the biotypes (Figure 3). When the line for expected equal height in competition was compared to actual plant height in competition there was a difference in slope, -1.80 vs. -1.19 respectively ($P = 0.0813$); and y-intercept (I), 315.1 vs. 283.4 respectively ($P = 0.0613$). The line of the competitive RYT was below the expected yield line and indicated that there was a negative competitive effect between the two biotypes. The lines for expected biomass compared to actual biomass in competition were similar in slope ($P = 0.1859$), but had marginally different I, 59.5 vs. 49.5 ($P = 0.0880$). This indicated that the lines are parallel and that the ratio of biomass production was similar between the biotypes. The difference in intercept indicated that the biomass yield in actual competition was lower than expected which indicated that a negative interspecific interaction had taken place. No difference in slope or intercept was found when comparing grass bunch area ($P = 0.2542, 0.5637$ respectively) and was similar to results for basal area yield observed in the replacement series diagrams.

For RCC, all yield metrics indicated that RM had greater competitive ability than EW. Values greater than 1.0 indicate that greater yield was generated from competition than would have been expected in monoculture (Table 2) and that intraspecific was greater than interspecific competition for RM. All RCC values for EW are the reciprocals of RM values and are therefore below 1. RCC values below 1 indicate that growth of the EW biotype was suppressed by RM in respect to expected monoculture yields. RCC values below 1 also indicate that growth with RM had a greater effect on yield than intraspecific competition.

Although ploidy level was not confirmed, biotypes of two differing ploidy levels could explain the results. The results align with current hypotheses about ploidy level and competitive

ability, advantage, and succession in this and other species (Bragg and McMillan 1962; Keeler 1992; Robertson 1974). It has been reported that diploid biotypes of species occur most often and are more competitive in areas that have stable, stress free growing conditions were the population has adapted (Stebbins 1985). In contrast, polyploids tend to be found in areas that have relatively more frequent disturbance (Mitchell 1992; Stebbins 1985) and relatively more stressful environments (Robertson 1974). For prairie junegrass, the biotypes that are found in areas of low rainfall and drought stress are polyploids, potentially represented by the EW biotype in this experiment, and varieties used in studies conducted by Robertson (1974). The competitive advantages expressed by the RM biotype in the current experiment under stress free, stable growing conditions suggest that it may be a diploid variety compared with EW. The advantages can be seen in the replacement series diagrams, where RM is a straight line and reduced EW biomass is concave. Competitive advantages are also perceived where RM RCC values are well over 1.0, the level of equal competition, contrasted with EW RCC values all under 1.0. The competitive advantage seen here does not suggest that all diploid biotypes of junegrass would perform better than polyploid biotypes. Further study of these biotypes to determine ploidy level is needed. It would also be of interest to grow these biotypes under different conditions of stress and determine if they respond similarly to this study, where RM was more competitive than EW, or if differences arise. Prairie junegrass breeding programs are focused on development of germplasm for use in different environments (Woosaree 2004). The information presented here would be useful in further selection of biotypes for prairie restoration and turfgrass uses (Watkins 2009) that better fit specific local growing conditions.

Source of Materials

[1] Seedling tray, BLK200S. McConkey Co., PO Box 1690, Sumner, WA, 98390-0369.

[2] Potting media, LC1 Sunshine Mix. Sun Gro Horticulture Distribution Inc., 15831 N. E. 8th St. Suite 100, Bellevue, WA 98008.

[3] Osmocote 14-14-14 slow release fertilizer. Scotts Company, 14111 Scottslawn Rd., Marysville, OH 43041.

[4] SAS software, Version 9.2. SAS Institute Inc., Box 8000, SAS Circle, Cary, NC 27513.

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Table 1. Values for each biotype grown in monoculture at 370 days after planting.

Biotype	Mean height* cm	Mean basal area cm^2	Mean dry biomass g
Rocky Mountain (RM)	269.06b	44.40a	72.14a
Rose Creek (EW)	315.13a	35.37a	59.53b
P-value	0.0187	0.1877	0.0328

* Means in the same column followed by a common letter are not different according to Fisher's Protected LSD test at $P \leq 0.05$.

Table 2. Relative crowding coefficients (RCC) for all indicators of yield where values of RCC = 1.0 indicate no advantage for either species in the mix; RCC < 1.0 indicate that species is producing less biomass then in monoculture; and RCC > 1.0 indicate species that are performing better than in monoculture, thus having a competitive advantage.

Biotype	Mean height	Mean basal area	Mean dry biomass
Rocky Mountain (RM)	1.125	1.369	1.51
Rose Creek (EW)	0.889	0.730	0.660

Figure 1. Replacement series diagrams for each indicator of yield taken: height, dry biomass, and grass bunch area. Rocky Mountain biotype (RM) closed circle, ●; eastern Washington biotype (EW) open circle, ○; and combined yield as a closed triangle, ▼; with bars indicating standard error.
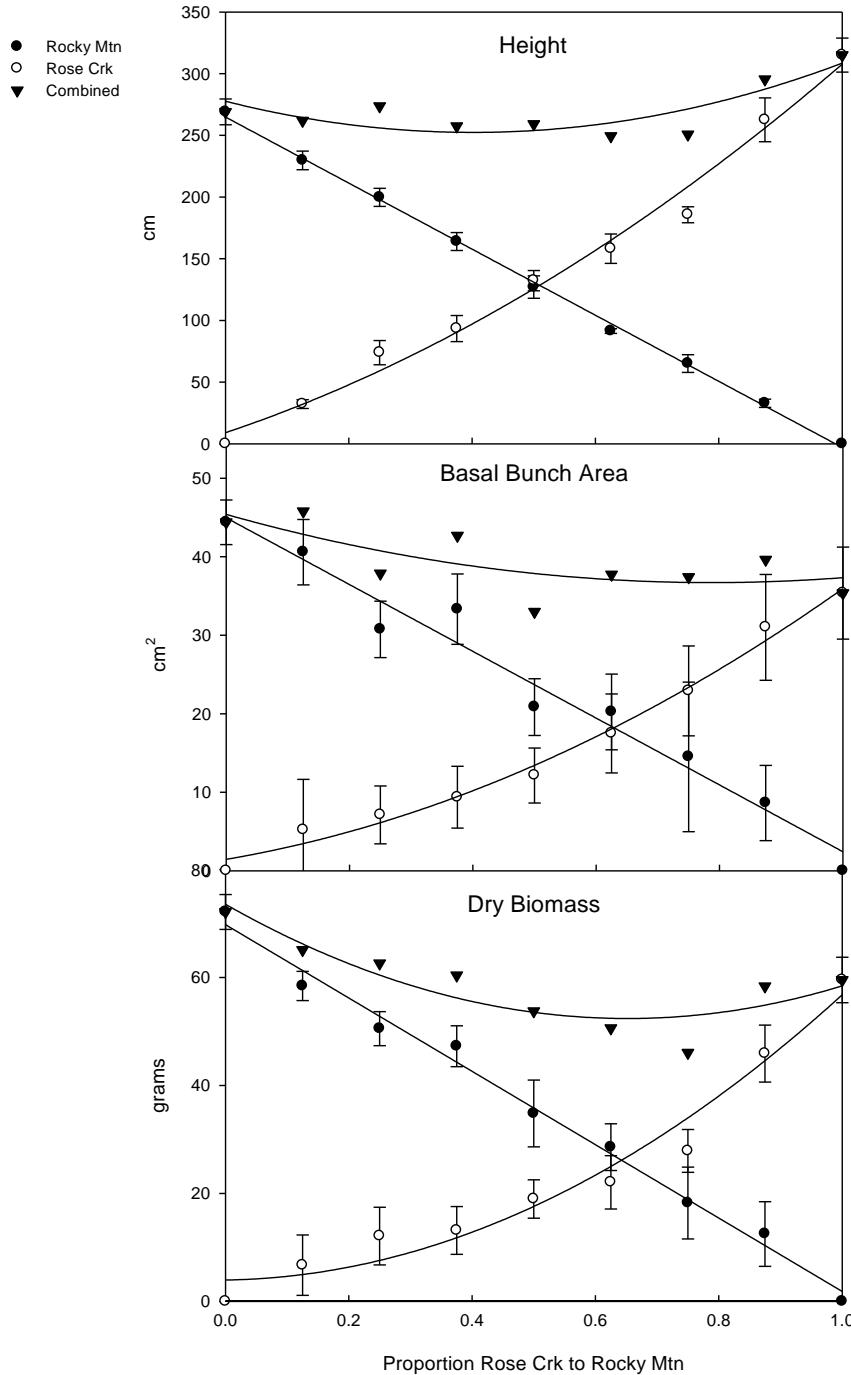
Figure 2. Relative Yield (RY) for each indicator of yield taken: height, grass bunch area, and dry biomass. Each point indicates a RY pair for across all planting ratios. The line across each graph is $RY_{RM} = RY_{EW}$ indicating instances of equal competitive advantage. Below the line denotes a competitive advantage of the Rocky Mountain (RM) over the Rose Creek biotype (EW), and above the line a competitive advantage of EW over RM.
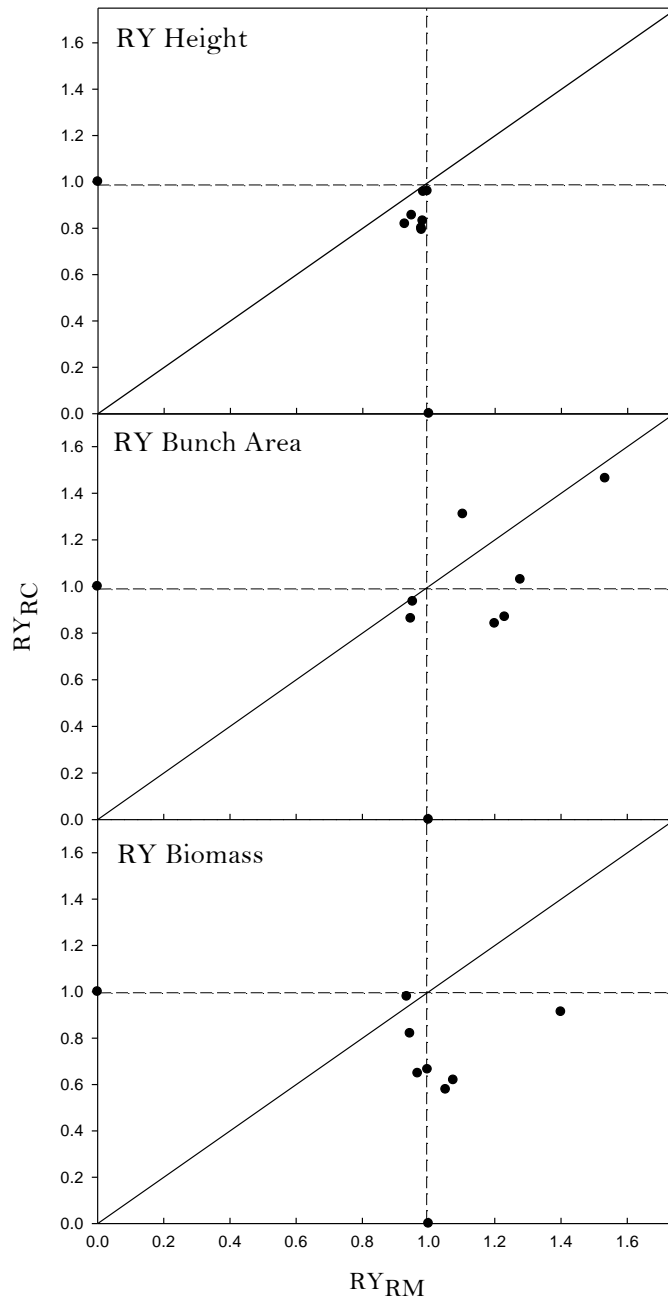
Figure 3. Relative Yield Total (RYT) across all indicators of yield: height, grass bunch area, and dry biomass. Points indicate the yield of the Rose Creek (EW) graphed over the Rocky Mountain biotype (RM) at each ratio level. The solid line (—) indicates expected yield in monoculture or without either biotype showing a competitive advantage. The broken line (- - -) indicates the actual yield measured in the presence of competition.
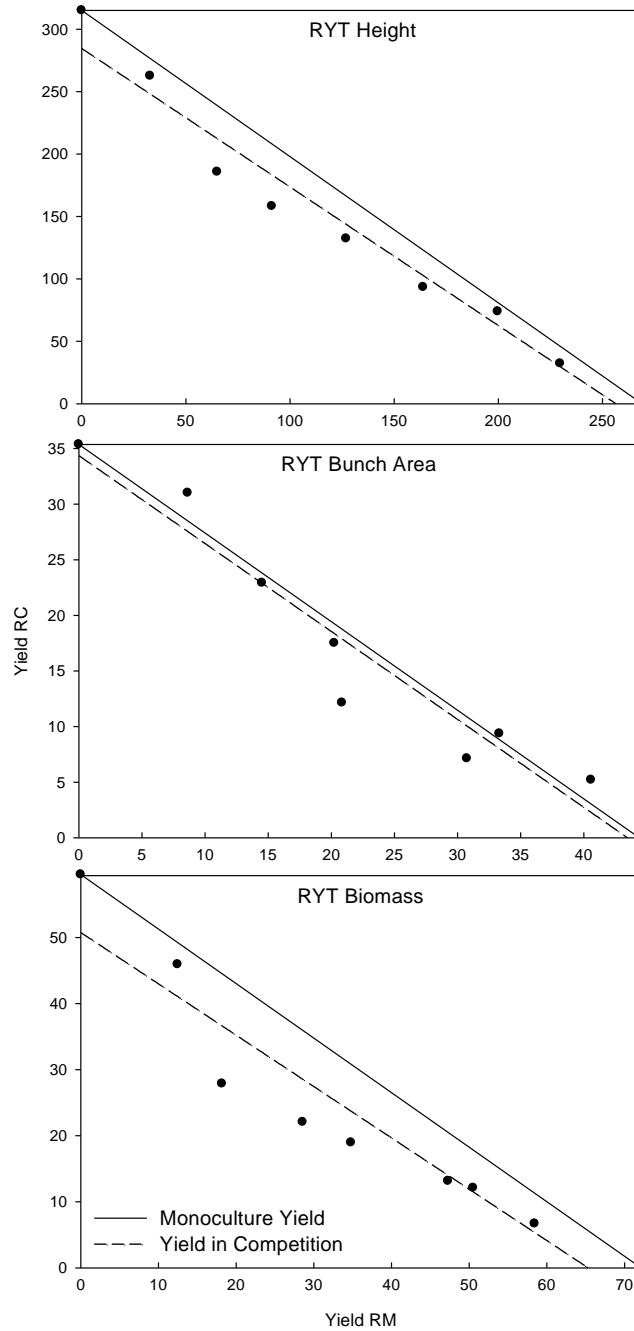
Management of Invasive Species in Native Palouse Prairie

Randall E. Stevens and Ian C. Burke[2]

Abstract

The Palouse Prairie ecosystem is endangered and the remnants are being further degraded by invasive species such as downy brome (*Bromus tectorum* L) and ventenata (*Ventenata dubia* (Leers) Coss.). This study evaluated the efficacy of registered and non-registered herbicides for control of grassy weeds for prairie restoration and recovery. The trial consisted of 4 sites, each with 3 replications arranged in a RCBD. The herbicide treatments applied were chlorsulfuron at 30 g/ha, diclofop at 1120 g/ha, imazapic at 140 g/ha plus glyphosate at 190 g/ha, mesosulfuron at 190 g/ha, metribuzin at 600 g/ha, propoxycarbazone at 40 g/ha pyroxsulam at 230 g/ha, or sulfosulfuron at 50 g /ha. A nontreated control was included for comparison purposes. A nonionic surfactant was applied with all herbicide at 0.5% v/v. Cover and richness data was taken using a 50 x 20cm frame in the center of each plot and was separated into functional groups based on native status and growth habit. The groups were: total natives, native forbs, native grasses, native shrubs, total alien, alien forbs, and alien grasses. Pyroxsulam, diclofop, and propoxycarbazone treatments were similar and had the greatest increase in species richness for total native plants over the nontreated, 5.0, 4.4, and 4.4 species/quadrat respectively (P >0.0012). Pyroxsulam, sulfosulfuron, and imazapic plus glyphosate treatments reduced alien

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grass richness to 0.9, 0.8, and 0.8 species/quadrat, respectively, compared to 1.8 for the

nontreated areas (P >0.0032). Total native and native forbs cover increased the most over

nontreated plots with the application of pyroxsulam, 97% (P > 0.0363) and 88% (P > 0.0235),

respectively. Imazapic plus glyphosate and sulfosulfuron provided the greatest reduction in alien

grass cover, 73% and 69% respectively, and were similar in control to pyroxsulam,

chlorsulfuron, and diclofop (P <0.0307). Sulfosulfuron and imazapic plus glyphosate

applications provided 87% or greater control of downy brome (P<0.0001). Diclofop showed

similar control to the imazapic plus glyphosate treatment. Ventenata was controlled 77% or

better similarly by diclofop, sulfosulfuron, pyroxsulam, and imazapic plus glyphosate.

Chlorsulfuron and mesosulfuron showed 56% or better control of ventenata and were

comparable to pyroxsulam and imazapic plus glyphosate treatments. Treatments of diclofop,

sulfosulfuron, pyroxsulam, and imazapic plus glyphosate had the greatest efficacy on grassy

weeds while maintaining the greatest safety on native species.

Nomenclature: Chlorsulfuron; diclofop; imazapic plus glyphosate; mesosulfuron; metribuzin;

propoxycarbazone; pyroxsulam; sulfosulfuron; downy brome, *Bromus tectorum* L.; ventenata,

Ventenata dubia (Leers) Coss..

Keywords: Palouse prairie, cover, species richness.

Introduction

The Palouse prairie originally encompassed a region in the Pacific Northwest extending east from the Cascade Mountains of Washington and Oregon into Idaho, east into Montana, south into Utah, and north into British Columbia (Lichthardt and Moseley 1997). For the purpose of this study however it will refer to the prairie grassland system within the geographical region of the Palouse in southeastern Washington and neighboring parts of northern Idaho. The Palouse region is defined physically by rolling hills of wind deposited loess soils over a basalt rock base layer (Lichthardt and Moseley 1997; Sánchez-de León and Johnson-Maynard 2009). Due to agricultural practices that converted grasslands to crop production more than 100 years ago (Daubenmire 1940; Tisdale 1961) the Palouse prairie in this region is rare and is limited to small remnant patches (Aller, et al. 1981; Lichthardt and Moseley 1997). Less than 0.1% of the Palouse remains unaltered and it is considered the most endangered ecosystem in the United States (Noss et al. 1995). Most of the fragmented remnants are small areas of land that consist of eyebrows, steep banks, areas of shallow soils and rock, and other areas that were unsuitable for agricultural production (Lichthardt and Moseley 1997). A survey of Palouse prairie remnants found that 510 of the 1,003 identified were less than 1 ha in size, and 91.2% of the total remnant area was privately owned (Looney and Eigenbrode 2008). Disturbances near to and in the remnants have led to an increase in alien grasses, mainly annual brome species, *Bromus spp.* (Lichthardt and Moseley 1997).

Mechanical means, such as tillage, can control downy brome if seed is buried to a depth of at least 6.4 cm (Hulbert 1955). Mowing is often not successful for control because mowed downy brome will continually set seed until the ripening stage, at which time the seed is viable. However, these mechanical methods can cause damage to desired native plant communities, and

in the case of the Palouse prairie, remnants were often left because they were not tillable in the first place due to steep slopes or shallow rocky soils.

Relatively few herbicides are registered for use in non-crop areas such as these prairie remnants. Even fewer have data supporting efficacy on native grasses and forbs. Many of the products that would provide control of downy brome and other invasive grasses could potentially harm more desirable species. Of the limited number of herbicides registered for use in non-crop and rangeland areas a few, such as, control downy brome, but variable control has also been reported and herbicide resistance can be an issue (Butler et al. 2008; Butler and Crockett 2008; Ball and Mallory-Smith 2000; Mallory-Smith et al. 1999; Park and Mallory-Smith 2004). In a study conducted on central Oregon rangeland a November application of imazapic at 0.21 kg ae/ha plus glyphosate at 0.42 kg ae/ha achieved 100% control of downy brome (*Bromus tectorum* L.) and medusahead (*Taeniatherum caput-medusae* (L.) Nevski) (Butler et al. 2008). A similar study in Oregon found that applications of sulfosulfuron at 43 g ai/ha controlled downy brome from 45 to 68% depending on location (Butler and Crockett 2008). A study on the effects of sulfosulfuron applied at 70 g/ha on downy brome and other grasses also found a reduction in photosynthetic activity of ranging from 76 to 100% after application (Monaco and Creech 2004). The registration of imazapic plus glyphosate (Anonymous 2008) may be an alternative that could yield similar control on downy brome and other undesired annual grasses.

The identification of new or alternative chemical control inputs for use in prairie systems need to be identified to expand the limited management tools used to control invasive species. Little is known about the effect of herbicides on pre agricultural Palouse Prairie species. Invasive species removal could initiate a seral change allowing for recovery of degraded site that is returning the native species to functional ecosystem. Research to evaluate the efficacy of

currently registered and non-registered herbicides for the control of invasive grass weeds such as downy brome and ventenata in Palouse Prairie is needed. As effects on non-target vegetation are highly undesirable, the effect on and response of the desirable native plant community was also evaluated. Because the native remnants are rare and potentially highly susceptible to further alien plant invasion, management options that are relatively low impact in application and effect on native species while at the same time show high efficacy on alien species are needed.

Materials and Methods

Experimental Sites. In late May, 2008 4 study sites were established on Smoot Hill, a 324 ha biological preserve owned by Washington State University, 3.2 km north of Albion, WA (46°49'05 N, 117°14'16 W). Study sites were located in areas of the preserve that had not been previously cultivated and were chosen based on the presence of vegetation associated with remnant Palouse prairie and had minimal landscape irregularities such as rock outcroppings and prairie mounds. The sites were also selected for cover that appeared to be dominated by a grass and forb community structure and were free of trees and woody plants over 0.4 m in height. The climate is characterized as having cool wet winters and hot dry summers with approximately 75% of the 54 cm of annual precipitation falling between November and April. The soil of the 922 m high hill is classified as Tekoa silt loam (loamy-skeletal, mixed, superactive, mesic Vitrandic Argixerolls).

At each of the sites three blocks were established along a transect running parallel to the slope of the hill. Each site faced a different cardinal direction. Each block contained nine 2.13 m^2 plots in 3 plot by 3 plot square configuration. At the center of each plot a 20 x 50 cm area was permanently marked with wire flags for the placement of a metal quadrat frame used for

sampling. Sites and plots were kept small to minimize any potential negative impacts on this

rare ecosystem. The decision to select site locations on differing aspects and arranging plots

parallel to the slope rather than across the contour was made in order to maximize the number of

species encountered to better assess the efficacy and impact of the treatments on the community.

Treatments. The trial was a RCBD and was repeated at each of the four sites. The trial

consisted of three blocks of nine plots that consisted of eight herbicide treatments and a

nontreated control plot for comparison purposes. The herbicide treatments applied were

chlorsulfuron at 30 g/ha, diclofop at 1120 g/ha, imazapic at 140 g/ha plus glyphosate at 190 g/ha,

mesosulfuron at 190 g/ha, metribuzin at 600 g/ha, propoxycarbazone at 40 g/ha pyroxsulam at

230 g/ha, or sulfosulfuron at 50 g /ha. A nonionic surfactant was applied with all herbicide

treatments at 0.5% v/v. Treatments were applied November 14th, 2008 at a time when native

species had senesced. Downy brome had emerged and averaged one leaf at 2.5 cm in height.

Herbicides were applied with a CO_2-pressurized backpack sprayer equipped with a handheld

boom with 4 flat fan nozzles[1] calibrated to deliver 187 L/ha. Nozzles were spaced 50 cm apart.

Data collection and statistical analysis. The vegetation in the established quadrat of each plot

was systematically sampled using the methods originally described by Duabenmire (1959) for

cover and richness. On May 27, 2009 a 50 x 20 cm rectangle frame was set down to delineate

the quadrat boundaries and canopy coverage measurements were made by estimating the range

of percent area of the frame covered by each species present. Ranges were 1 to 5%, 6 to 25%, 26

to 50%, 51 to 75%, 76 to 95%, and 96 to 100%, and median of the coverage range was recorded

as the score (Daubenmire 1959). Richness was tabulated as the number of species present in

each quadrat. Cover and richness data was assembled into functional groups based on native

status and growth habit. The data was categorized into these groups: total natives, native forbs,

native grasses, native shrubs, total alien, alien forbs, and alien grasses. On July 9, 2009 downy

brome and venenata control was estimated visually on a scale from 0 (no control) to 100

(complete control) (Frans et al. 1986).

Data were tested for homogeneity of variance by plotting residuals. Richness and cover

data were arcsine square root transformed, which improved data homogeneity. To recognize

treatment structure in the factorial treatment arrangement, ANOVA was conducted using the

MIXED procedure in SAS[2] with sums of squares partitioned to reflect trial and herbicide

treatment effects. Sums of squares were partitioned to evaluate study location effects

(considered fixed) and treatments. Main effects and block interactions were tested by the

appropriate mean square associated with the fixed variables (McIntosh 1983). ANOVA

indicated no significant trial main effects, so data were pooled over trials for analysis. Means

separations were performed on transformed data using Fisher's protected LSD at $P = 0.05$.

Nontransformed data are presented for clarity.

Results and Discussion

Forb species had the greatest richness. Forbs represented 26 of the 35 species detected,

19 of which were native and 7 alien (Table 1). This agrees with other cover data studies that

show a high proportion of forbs in this plant association (Daubenmire 1970; Lichthardt and

Moseley 1997). Grasses had the second highest richness with 7 species, 3 native and 4 alien.

Native shrubs had the lowest richness with just 2 species sampled. Native and alien species both

covered about 27% of each quadrat (Table 3). Of the total native cover 50% was forbs, 34%

grasses, and the remaining 16% was shrubs. Alien grasses made up 82% of the total alien cover

and the forbs the remaining 18%. The remaining space in the quadrat was bare ground or areas

covered with duff. Although native forbs were the most abundant, alien grasses had the highest

cover area and were the most dominant species in the study.

Herbicide treatment effects were detected for species richness for total native species,

native forbs, alien grasses, and alien forbs (Table 2). Pyroxsulam, diclofop, and

propoxycarbazone had the highest total number of native species, 5.0, 4.4, and 4.4

species/quadrat respectively (P >0.0012). Metribuzin, mesosulfuron, sulfosulfuron, and

imazapic plus glyphosate treatments were similar and did not change the total native plant

richness compared to the nontreated. Native forb richness was greater with pyroxsulam and

diclofop applications, while an application of chlorsulfuron decreased native forb richness (P

>0.0002). Metribuzin, mesosulfuron, imazapic plus glyphosate, propoxycarbazone, and

sulfosulfuron treatments did not affect native forbs richness. Chlorsulfuron also decreased alien

forbs richness, while the other treatments did not (P >0.0135). Although an increase in native

richness was not anticipated, a decrease would be undesirable as it would indicate control of the

native species. Treatments that did not reduce native species richness represent safe treatments.

Pyroxsulam, sulfosulfuron, and imazapic plus glyphosate treatments reduced alien grass

richness to 0.9, 0.8, and 0.8 species/quadrat, respectively, compared to 1.8 species/quadrat for

the nontreated areas (P >0.0032). Chlorsulfuron, propoxycarbazone, mesosulfuron, metribuzin,

and diclofop treatments had similar alien grass richness to the nontreated areas.

For cover, there was a significant herbicide treatment effect on the native plants, native

forbs, and alien grasses (Table 3). Total native plant and native forb cover was greater than the

nontreated (27.1% and 13.5%) with pyroxsulam, 53.3% (P > 0.0363) and 36.7% (P > 0.0235),

respectively. All other treatments had similar native plant and native forb cover as the

nontreated area. In imazapic plus glyphosate and sulfosulfuron treatments, alien grass cover was

6.0% and 6.9% respectively, and was similar to alien grass cover in pyroxsulam, chlorsulfuron, and diclofop and less than nontreated areas and other treatments (P <0.0307). No difference in the cover of native grasses, native shrubs, total alien species, or alien forbs was detected. Sulfosulfuron and imazapic plus glyphosate applications provided 87% or greater control of downy brome (P<0.0001) (Table 4). Control with diclofop was similar to the control with imazapic plus glyphosate. Propoxycarbazone, metribuzin, pyroxsulam, mesosulfuron, and chlorsulfuron were similar and had less than 55% downy brome control. Ventenata control was 77% or better with applications of diclofop, sulfosulfuron, pyroxsulam, and imazapic plus glyphosate. Chlorsulfuron and mesosulfuron had 56% or better control of ventenata and were comparable to pyroxsulam and imazapic plus glyphosate treatments. Metribuzin and propoxycarbazone treatments had comparable ventenata control of less than 49%. Propoxycarbazone applications were also similar to the nontreated control.

Morris and coworkers (2009) observed control of downy brome with increasing rates of imazapic. Cover after the first year was 12% at the highest imazapic rate compared to > 80% initially. They also inter-seeded desired grass species at the same time. However, after two years all sites had returned to pretreatment cover levels of downy brome regardless of treatment. They found a tradeoff between desirable grass establishment and downy brome control as well, where higher establishment rates were able to suppress downy brome reestablishment longer, and that higher control with increased rates of herbicides positively correlated with desired grass establishment. Morris and coworkers (2009) concluded that higher control prior to establishment as well as increased native establishment was needed to maintain downy brome suppression long term. A similar study using imazapic for downy brome and alien forbs control in rangeland fire break establishment also observed a 2 year suppression of downy brome, redstem filaree

(*Erodium cicutarium* (L.) L'Hér. ex Ait), and tumble mustard (*Sisymbrium altissimum* L.) that

allowed seeded grasses to establish (Davidson and Smith 2007). A natural increase in native

forbs was also observed. The results from these studies suggests that there is a threshold of alien

species present balanced with the number of native species in an area and the ability of that area

to recover from invasion and resist future weed pressure. An increased diversity of functional

native plant groups increase the resistance to the invasion of a community and greater richness

and diversity of species within the functional group similar to alien species lower the chance of

that alien establishing (Pokorny et al. 2005; Woods 1997). The Palouse remnants in the study

have native species in each of the functional groups. Those species present may help to facilitate

recovery over a longer period of time than the present study was conducted. Further monitoring

of the site should be conducted to test this hypothesis. The native grasses present are all

perennial species which can take longer to react to changes in dominance. Although native

grasses did not increase in richness or cover, it is positive to see that none of the treatments

negatively affected these parameters. Some herbicide injury was seen on perennial native

species but was not quantified for this study.

None of the treatments completely controlled or removed the alien grass species as

indicated by species richness. Lack of complete control suggests that herbicide applications

alone are not the only management input option required and that they should be used with other

methods to control problematic weeds. It may be useful to make multiple applications of these

chemicals in subsequent years to continue managing the weeds and reduce the soil seedbank.

Herbicide treatments could also be used in conjunction with a reseeding effort to remove non-

desirable grass species and replace them with desired grass species that fill a similar niche.

Through continued monitoring it is possible that one of the treatments applied has reduced the

competitive ability of the invasive grass species sufficiently to allow native succession to occur. Treatments of diclofop, sulfosulfuron, pyroxsulam, and imazapic plus glyphosate appear to have selective efficacy on alien grass species. Further studies with these herbicides on a broader spectrum of native and alien species should be investigated and possibly include treatments that look at rate, timing, and multiple application effects over a longer period of time.

Source of Materials

[1] XR11002VS flat fan nozzles, TeeJet spray nozzles. Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189.

[2] SAS software, Version 9.2. SAS Institute Inc., Box 8000, SAS Circle, Cary, NC 27513.

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Table 1. List of species detected within 4 sites on Smoot Hill by scientific name, common name, richness across all sites (107 plots), and richness in nontreated (12 plots).

Scientific name	Common name	Richness All treatments	Richness Nontreated
Native forbs	Sub total	101	11
Achillea millefolium L.	Common yarrow	51	3
Galium boreale L.	Northern bedstraw	36	4
Lithophragma parviflorum (Hook.) Nutt. ex Torr. & A. Gray	Prairiestar	22	1
Myosotis micrantha Pall ex Lehm.	Forget-me-not	53	5
Phlox speciosa Pursh	Showy phlox	6	0
Geranium pusillum L.	Small geranium	55	4
Balsamorhiza sagittata (Pursh) Nutt.	Arrowleaf balsamroot	5	0
Lomatium triternatum (Pursh) J. M. Coult & Rose	Nineleaf biscuitroot	12	2
Agoseris grandiflora (Nutt.) Greene	False dandelion	11	2
Lupinus sericeus ssp. *sericeus* Pursh	Silky lupine	3	0
Allium acuminatum Hook.	Wild onion	12	2
Helianthella uniflora (Nutt.) T. & G.	False sunflower	5	1
Lomatium dissectum (Nutt. ex T. & G.) Mathias & Const.	Desert parsley	16	0
Collinsia parviflora Dougl. ex. Lindl.	Maiden blue eyed Mary	20	2
Fritillaria pudica (Pursh) Spreng.	Yellow fritillary	5	1
Claytonia perfoliata Donn.	Miner's lettuce	2	1
Potentilla gracillis Dougl. ex Hook.	Slender cinquefoil	4	0
Olsynium douglasii (A. Dietr.) E.P. Bicknell	Grass widow	6	1
Native grasses	Sub total	56	6
Leymus cinereus (Scribn. & Merr.) A. Löve	Basin wild rye	15	1

Pseudoroegneria spicata (Pursh) A. Löve	Bluebunch wheatgrass	15	0
Festuca idahoensis Elmer	Idaho fescue	35	5
Native shrubs	Sub total	21	2
Symphoricarpos albus (L.) Blake var. albus	Common snowberry	19	2
Rosa woodsii Lindl.	Woods Rose	2	0
Alien forbs	Sub total	80	8
Draba verna L.	Whitlow grass	3	1
Epilobium brachycarpum C. Presel	Willow herb	45	8
Amsinckia spp.	Fiddleneck	13	1
Cirsium arvense (L.) Scop.	Canada thistle	1	0
Tragopogon dubias Scop.	Western salsify	1	0
Sisymbrium altissimum L.	Tumble mustard	5	1
Lactuca serriola L.	Prickly Lettuce	57	3
Alien grasses	Sub total	89	12
Bromus tectorum L.	Downy Brome	85	10
Ventenata dubia (Leers) Coss.	Ventenata	29	5
Poa bulbosa L.	Bulbous bluegrass	5	1
Bromus briziformis Fisch. & Mey.	Rattlesnake brome	17	5

Table 2. Herbicide treatment effect on mean species richness. Species richness is equal to the number of species present in each plot, and subdivided into functional groups.

Treatment[c]	Rate g ai/ha	Native plant cover (%)				Alien plant cover (%)		
		Total[a]	Forbs	Grass	Shrub	Total	Forbs	Grass
Nontreated	-	3.2cd	2.5c	0.5	0.2	2.9	1.2a	1.8a
Pyroxsulam	230	5.0a	4.0a	0.8	0.2	2.1	1.2a	0.9bc
Diclofop	1,120	4.4ab	3.8ab	0.5	0.2	2.7	1.5a	1.2abc
Metribuzin	600	4.3abc	3.5abc	0.5	0.3	2.6	1.2a	1.4ab
Mesosulfuron	190	4.0abc	3.1abc	0.7	0.2	2.5	1.2a	1.4ab
Imazapic + glyphosate	140 190[b]	3.6abc	2.7bc	0.7	0.3	1.8	1.1a	0.8c
Propoxycarbazone	40	4.4ab	3.4abc	0.8	0.2	2.8	1.3a	1.6ab
Sulfosulfuron	50	3.6bc	3.0abc	0.3	0.3	2.3	1.6a	0.8c
Chlorsulfuron	30	2.3d	1.5d	0.6	0.2	2.2	0.4b	1.8a

[a] Letters following means within each column indicate a significant difference as determined by Fisher's Protected LSD ($P <$ 0.05) when a treatment main effect was detected.

[b] Glyphosate rate expressed in g ae/ha.

[c] Nonionic surfactant was applied with all herbicide at 0.5% v/v.

Table 3. Herbicide treatment effect on mean species cover.

Treatment[c]	Rate g ai/ha	Native plant cover (%) Total[a]	Forbs	Grass	Shrub	Alien plant cover (%) Total	Forbs	Grass
Nontreated	-	27.1bc	13.5bc	9.2	4.4	27.3	5.0	22.3ab
Pyroxsulam	230	53.3a	36.7a	14.2	2.5	25.2	7.1	18.1abc
Diclofop	1,120	39.4ab	27.7ab	6.3	5.4	24.0	16.9	7.1bc
Metribuzin	600	32.3ab	25.4ab	2.3	4.6	29.6	8.1	21.5ab
Mesosulfuron	190	39.5abc	24.1bc	9.5	5.9	29.5	6.4	23.2a
Imazapic + glyphosate	140 190[b]	30.6abc	22.1bc	4.8	3.8	14.8	8.8	6.0c
Propoxycarbazone	40	30.2abc	19.8abc	7.1	3.3	38.3	8.3	30.0ab
Sulfosulfuron	50	43.3bc	37.9abc	1.9	3.5	16.9	10.0	6.9c
Chlorsulfuron	30	16.7c	9.8c	3.5	3.3	19.4	2.1	17.3abc

[a] Letters following means within each column indicate a significant difference as determined by Fisher's Protected LSD ($P < 0.05$) when a treatment main effect was detected.

[b] Glyphosate rate expressed in g ae/ha.

[c] Nonionic surfactant was applied with all herbicide at 0.5% v

Table 4. Herbicide control of targeted invasive grasses. On a scale of 0 (no control) to 100 (complete control).

Treatment[c]	Rate g ai/ha	Downy brome % Control[a]	Ventenata % Control[a]
Nontreated	-	0e	0e
Pyroxsulam	230	40cd	77ab
Diclofop	1,120	61bc	90a
Metribuzin	600	50cd	49cd
Mesosulfuron	190	36d	56bc
Imazapic + glyphosate	140 190[b]	87ab	77ab
Propoxycarbazone	40	55cd	28de
Sulfosulfuron	50	90a	90a
Chlorsulfuron	30	34cd	62bc

[a] Letters following means within each column indicate a significant difference as determined by Fisher's Protected LSD ($P <$ 0.05) when a treatment main effect was detected.

[b] Glyphosate rate expressed in g ae/ha.

[c] Nonionic surfactant was applied with all herbicide at 0.5% v