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Original Research

Revegetation of Medusahead-Invaded Rangelands in the Channeled Scablands of Eastern Washington☆,☆☆

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ABSTRACT

Vegetation on the Channeled Scablands of eastern Washington has been altered to a community dominated by medusahead (*Taeniatherum caput-medusae* [L.] Nevski). Medusahead is used by livestock but becomes unpalatable as the plant matures and seed heads develop, thus decreasing carrying capacity. The objective of this study was to determine if improved cool-season grasses could establish and persist on medusahead-infested rangelands in the region. A split-plot randomized complete block design consisting of four blocks was established at three different locations. Plots were treated with herbicides to remove all vegetation and seeded in 2010. Seeded species included introduced cool-season grass cultivars: Hycrest II crested wheatgrass (*Agropyron cristatum* [L.] Gaertn.), Vavilov II Siberian wheatgrass (*Agropyron fragile* [Roth] P. Candargy), Bozoisky II Russian wildrye (*Psathyrostachys juncea* [Fisch.] Nevski), and a native cool-season grass mix composed of Sherman big bluegrass (*Poa secunda* J. Presl), Secar Snake River wheatgrass (*Elymus wawawaiensis* J. Carlson & Barkworth), Bannock Thickspike wheatgrass (*Elymus lanceolatus* [Scribn. & J. G. Sm.] Gould), and Recovery Western wheatgrass (*Pascopyrum smithii* [Rydb.] Á Löve). Sherman big bluegrass was the only native species that established, and frequency was 65% at the end of the study. Hycrest II frequency was 48% at the end of the study. Vavilov II frequency was 50% at the end of the study. Sherman big bluegrass matured early in the season and had greater biomass production than Hycrest II and Vavilov II in May. The later-maturing Hycrest II and Vavilov II were similar in biomass production to Sherman big bluegrass in July. Bozoisky II had poor stand establishment and did not persist. Hycrest II, Vavilov II, and Sherman big bluegrass are forages that can be used for revegetation on the Channeled Scablands of eastern Washington.

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Introduction

Grazing was of limited importance in the Channeled Scablands of eastern Washington before arrival of European-American settlers (Daubenmire, 1970; Galbraith and Anderson, 1971). The first intensive grazing pressure in Washington ranges occurred from horses (Harris, 1991). In the 1700s, domesticated horses were introduced to Indian tribes from the Shoshone tribe of southern Idaho (Haines, 1938). Cattle were introduced in 1834 (Daubenmire, 1970) and sheep around 1860 (Franklin and Dyrness, 1973). Reports of 200 000 livestock and feral horses were present by 1855 (Daubenmire, 1970), and ranges became fully stocked in the early 1870s (Harris, 1991). Sheep were generally more abundant than cattle until about 1940 (Franklin and Dyrness, 1973). Overgrazing occurred throughout the region from the late-1800s to the mid-1900s, leading to degradation of native vegetation in the region (Pyke and Borman, 1993).

As settlers moved into the region, they introduced exotic alien plants (Mack, 1986). Downy brome (*Bromus tectorum* L.) was collected in 1893 near the railroads in Ritzville, Washington and became a dominant species in the steppe of the Intermountain West by 1930 (Mack, 1981). Medusahead (*Taeniatherum caput-medusae* [L.] Nevski) specimens were collected in Steptoe Butte in eastern Washington in 1901 (Piper and Beattie, 1914). Heavy use of downy brome by livestock in the early spring reduces seed bank retention and stand abundance (Daubenmire, 1940; Vallentine and Stevens, 1994), providing an opportunity for the less desirable medusahead to become the dominant exotic annual grass. Medusahead decreases biological diversity, reduces livestock forage production, degrades ecological function of native plant communities, and increases the frequency of wildfires on rangelands

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(D'Antonio and Vitousek, 1992; Davies and Svejcar, 2008; Davies, 2011). Medusahead invasion often results in near monocultures (George, 1992), decreasing forage value for livestock and decreasing grazing capacity by 50% to 80% (Hironaka, 1961).

The presence of medusahead has altered the natural succession of vegetation on the Channeled Scablands and reduced forage options for livestock (Pfister et al., 2014; Stonecipher et al., 2016), resulting in cattle using forbs such as velvet lupine (*Lupinus leucophyllus* Douglas ex Lindl.). Velvet lupine is native to the region and is widely distributed in eastern Washington (Weaver, 1915). Velvet lupine is poisonous and contains a quinolizidine alkaloid, anagyrine, which is teratogenic to cattle, between 40 and 100 d of gestation, resulting in a condition known as crooked calf syndrome (CCS; Keeler, 1976; Keeler and Panter, 1989). Cattle producers in the region live with a 1%—5% incidence of lupine-induced CCS each year (Lee et al., 2008). However, a catastrophic outbreak occurred in Adams County, Washington in 1997, where between 3 000 and 4 000 calves were born with lupine-induced skeletal malformations and some cattle operations lost 100% of their calf crop (Lee et al., 2008). One major management tool that has been suggested to help reduce the incidence of CCS is to improve range conditions providing an alternative forage source for cows during this critical period of gestation (Panter et al., 2013).

Due to the lack of desired vegetation, revegetation is necessary to change the flora from a medusahead-dominated plant community to a healthy perennial grassland (Sheley et al., 2007; Davies and Svejcar, 2008). Revegetation is necessary to increase forage value and abundance and provide an alternative forage source for livestock to help reduce the incidence of CCS. The objective of this study was to determine if improved cool-season grass cultivars can establish and persist after medusahead and other vegetation are controlled with herbicides and, thus, increase forage production on the Channeled Scablands as a management tool to prevent lupine-induced CCS. We hypothesized that 1) improved introduced grass cultivars would establish and persist, reduce medusahead and other weeds, and increase forage production and 2) improved native grass cultivars would establish and persist, reduce medusahead and other weeds, and increase forage production.

Methods

The study was located in the Channeled Scablands within the Columbia Plateau of eastern Washington. Glacial floods swept across 7 770 km^2 (3 000 mi^2) of the Columbia Plateau removing the overlying loess and silt with > 5 180 km^2 (2 000 mi^2) cut directly into the basalt, leaving the channeled floors bare and eroded, creating the Channeled Scablands (Bretz, 1923). Elevation and precipitation vary throughout the region. Elevation in the western and central portions range from 366 to 183 m (USDA, NRCS, 2016) and receive the least amount of precipitation between 150 and 250 mm annually (USDA, NRCS, 2016). Elevation gradually increases toward the east, northeast, and south to 1219 m in the mountains (Weaver, 1917) and annual precipitation increases between 400 and 600 mm (Franklin and Dyrness, 1973). The original plant community was classified as a sagebrush steppe in the drier areas (Daubenmire, 1970; West and Young, 2000) and Palouse prairie to the east as precipitation increases (Daubenmire, 1970; Sims and Risser, 2000). Much of the vegetation on the deep fertile soil has been converted to agriculture cropland (Dobler et al., 1996; Quigley and Arbelbide, 1997), whereas any remaining native vegetation is found on rocky soils that are difficult to cultivate and have been overgrazed by livestock. As a result, vegetation on the Channeled Scablands has been degraded to a state dominated by the annual grass species, downy brome, and medusahead (Ralphs et al., 2011a). Other plant species consist of perennial grasses such as Sandberg bluegrass (*Poa secunda* J. Presl) and bulbous bluegrass (*Poa bulbosa* L.) and weedy forbs such as fiddleneck (*Amsinckia intermedia* Fisch. & C.A. Mey), tansy mustard (*Descurainia pinnata* [Walter] Britton), rush skeletonweed (*Chondrilla juncea* L.), black mustard (*Brassica nigra* [L.] W.D.J. Koch), filaree (*Erodium cicutarium* [L.] L'Hér. Ex Aiton), prickly lettuce (*Lactuca serriola* L.), and western salsify (*Tragopogon dubius* Scop.) (Ralphs et al., 2011b).

Plot Site Description

Plots were established on three ranches spanning a 33-km transect of the Scablands to take advantage of the different rangeland conditions, environmental factors, and variations in microclimates. Site N was located about 36 km south of Ritzville, Washington (46°48.23′N, 118°16.98′W, 434 m). The soil is a coarse-loamy over sandy or sandy skeletal, mixed, superactive, mesic calcidic haploxeroll (Stratford silt loam), and the ecological site is loamy within a 254-406 mm precipitation zone. Site C was located about 36 km southeast of Ritzville, Washington (46°50.29′N, 118°09.99′W, 469 m). The soil is a coarse-loamy over sandy or sandy-skeletal, mixed, superactive, mesic typic haploxeroll (Benge gravelly silt loam), and the ecological site is a loamy bottom within a 254 — 406 mm precipitation zone. Site S was located about 26 km southeast of Ritzville, Washington (47°03.16′N, 118°02.79′W, 553 m). The soil and ecological site is classified the same as Site C. The long-term mean annual precipitation is 254 mm with 60% of the precipitation occurring from September through February (NOAA, 2014).

Experimental Design

The study was laid out in a split-plot in a randomized complete block design consisting of four blocks per location. Each block consisted of eight plots (3 × 15 m) with seven different seeding treatments and one untreated control plot. All plants seeded in this study, their common and Latin names, mixture %, and germination rates are listed in Table 1. Seeded grasses included Vavilov II Siberian wheatgrass (*Agropyron fragile* [Roth] P. Candargy), Bozoisky II Russian wildrye (*Psathyrostachys juncea* [Fisch.] Nevski), Hycrest II crested wheatgrass (*Agropyron cristatum* [L.] Gaertn.), and a native cool-season grass mix composed of Sherman big bluegrass (*Poa secunda* J. Presl), Secar Snake River wheatgrass (*Elymus wawawaiensis* J. Carlson & Barkworth), Bannock Thickspike wheatgrass (*Elymus lanceolatus* [Scribn. & J. G. Sm.] Gould), and Recovery Western wheatgrass (*Pascopyrum smithii* [Rydb.] Á Löve). One cultivar Immigrant and two breeding lines of forage kochia (*Bassia prostrata* [L.] A. J. Scott) were interseeded with Vavilov II to make up the remaining three plots. Whole plots were divided into two subplots (3 × 7.5 m) with half of the plot disturbed with one pass by a chisel plow and harrow and the second pass with the harrow alone before planting. The remaining subplot was left undisturbed before planting.

With the exception of the control plot, plots were sprayed in the spring of 2009 with glyphosate (560 g ae · ha^{-1}) and 2,4-dichlorophenoxyacetic acid (2,4-D; 584 g ae · ha^{-1}) to remove existing vegetation using a CO_2-pressurized backpack at a rate of 153 L · ha^{-1}. The plots were sprayed again in the fall of 2009 with chlorsulfuron and sulfometuron methyl at a rate of 26 and 53 g ai · ha^{-1}, respectively, to remove the annual grasses and forbs that germinated after the first herbicide application. Plots were spot sprayed in June 2010 with glyphosate (560 g ae · ha^{-1}), 2,4-D (584 g ae · ha^{-1}), and picloram (560 g ae · ha^{-1}). Herbicides were combined with a 0.25% v/v nonionic surfactant (S-90 Surfactant, IFA-S90, Intermountain Farmers Association, Salt Lake City, UT).

Grasses were planted in November 2010 with a Truax no-till drill equipped with depth bands to ensure consistent seeding depth at 0.95 cm. Row spacing was 20.3 cm. Bozoisky II, Hycrest II, Vavilov II, and the native mix were seeded at a rate of 11.2 kg · ha^{-1} pure live seed. Forage kochia was seeded in January 2011 by dropping the seed on the ground using a Gandy drop spreader at a rate of 2.2 kg · ha^{-1}. All plots were mowed to a stubble height of 0.08 m on November 2011 and December 2012, to remove the previous year's growth.

Table 1
Plants seeded in the study, common and Latin names, mixture percent, and germination rates.

Variety	Common name	% of mix[2]	Scientific name	% PLS[3]
Native mix				
Sherman	Big bluegrass	5	*Poa secunda* J. Presl	88
Secar	Snake River wheatgrass	41	*Elymus wawawaiensis* J. Carlson & Barkworth	88
Bannock	Thickspike wheatgrass	21	*Elymus lanceolatus* (Scribn. & J. G. Sm.) Gould	91
Recovery	Western wheatgrass	33	*Pascopyrum smithii* (Rydb.) Á Löve	83
Hycrest II	Crested wheatgrass	—	*Agropyron cristatum* (L.) Gaertn.	90
Vavilov II	Siberian wheatgrass	—	*Agropyron fragile* (Roth) P. Candargy	89
Bozoisky II	Russian wildrye	—	*Psathyrostachys juncea* (Fish.) Nevski	92
Immigrant[1]	Forage kochia	—	*Bassia prostrata* (L.) A. J. Scott; syn. *Kochia prostrata* (L.) Schrad.	43
Sahro[1]	Forage kochia	—		54
Pustinny[1]	Forage kochia	—		30

PLS indicates pure live seed.
[1] Forage kochia species were interseeded with Vavilov II.
[2] Percent of each native grass species in the mix.
[3] Percent pure live seed.

Measurements

Foliar cover was estimated with the line-point intercept method (Herrick et al., 2005) before herbicide treatments in May 2009. Frequency of seeded grasses was measured in June 2011, the first year after seeding, within each subplot using visual estimates based on a one-to-nine rating and converted to a percentage (1 = 0%, 5 = 50%, 9 = 100%) as described in Robins et al. (2013). Visual estimates of percent frequency of weeds in the subplots were made at the same time using the same procedure. Weeds consisted of all other plant material in the subplots that were not seeded grasses. Frequency of seeded grasses was measured in July 2012 using the frequency grid described by Vogel and Masters (2001) consisting of 24 squares (four rows of six squares), each 10.2 × 10.2 cm (0.612 × 0.408 m frame). The number of squares containing at least one seeded plant was counted. The number of squares containing the seeded plants was divided by the maximum potential (24 squares) to obtain percent frequency of seeded species. The frame was systematically placed over the drill rows at two locations within each subplot at 3-m intervals alternating from the left to right side of the plot. Weeds were present in most of the squares within the frame and gave the appearance that the frequency of weeds were high (near 100%); however, they were actually reduced, which is evident from the weed biomass data and thus weed frequency data were not collected in 2012. A visual estimate was taken before clipping in 2013 using the same procedure as in 2011, which gave a better indication of weed frequency.

Aboveground standing crop biomass production was determined in May and July of 2012 and 2013 by hand-harvesting all vegetation in the 0.25-m^2 frame to an 8-cm stubble height. Within each subplot, two frames were clipped and combined into one sample. Samples were separated into two vegetation categories recorded as plant material: grasses, representing the seeded grasses, and weeds. Plant material was dried in a forced-air oven at 60°C to a constant weight. Dried samples were then ground in a Wiley mill to pass through a 1-mm screen. Ground plant samples were scanned with a Model 6500 near-infrared reflectance spectrometer (NIRS; Pacific Scientific Instruments, Silver Spring, MD) to estimate crude protein (CP), neutral detergent fiber (NDF), and in vitro true digestibility (IVTD). Representative samples were selected from each time period and used as a validation data set by wet chemical analyses (see later). The validation data set consisted of 141, 129, and 109 samples each for CP, NDF, and IVTD, respectively, which were not part of the NIRS equation. Samples used for calibration were analyzed for nitrogen (N) content with the combustion method (AOAC, 1996) using a Leco CHN-2000 Series Elemental Analyzer (Leco Corp., St. Joseph, MO). Levels of CP were determined by multiplying N content × 6.25. A two-stage method was used to determine IVTD with the first stage consisting of a 48-h in vitro fermentation in an ANKOM Daisy II incubator (ANKOM Technology Corp., Fairport, NY). Analyses of NDF and the second stage of the IVTD procedure were made using procedures modified for use in an ANKOM-200 Fiber Analyzer (ANKOM Technology Corp., Fairport, NY). The R^2 value for validation of CP was 0.95 (standard error of prediction [SEP] = 0.57). Corresponding R^2 values were 0.95 (SEP = 1.99) for NDF and 0.79 (SEP = 3.24) for IVTD.

Data Analyses

Due to the lack of forage kochia establishment in the Vavilov II plots, all plots containing Vavilov II were combined for analysis. Least squares means (LSMEANS) were determined for foliar cover, before the start of the study, as a randomized block design using generalized linear mixed-models (PROC GLIMMIX) method in a mixed-model analysis of variance (ANOVA) in SAS v. 9.3 (SAS Institute, Cary, NC). Plots were the experimental units, and the four blocks were the replicates. Seeded grasses were fixed effects, and location was a random factor in the model.

The effects of plant material and disturbance by months and years on biomass production and forage quality (CP, NDF, IVTD) were assessed using a mixed-model ANOVA of a 4-way factorial in a blocked split-plot design with repeated measures. The effects of plant material and disturbance by years on frequency were assessed using a mixed-model ANOVA of a 3-way factorial. Biomass, forage quality, and frequency values were averaged over blocks at each location, and the means were used as data in the analysis. Locations, plot, subplot, and repeated measures on a subplot were incorporated as random effects factors. Plant material, disturbance, year, and month were incorporated as fixed-effects factors. Plots within location were experimental units for levels of plant material. Subplots within plots and location were experimental units for disturbance. Repeated measures on subplots within plots and locations were experimental units for year and month. Biomass production was transformed with a square root transformation to meet assumptions of normality and homogeneity of variance. Treatment means were reported as original, nontransformed data with standard errors. Treatment means were separated using the LSMEANS method, and main effects were adjusted for Type I error inflation using the Tukey method. Data analysis was conducted using the GLIMMIX procedure in SAS v 9.3 (SAS Institute, Cary, NC; $P < 0.05$).

Results

Sherman big bluegrass was the only grass species that established in the native grass mix, and thus Sherman big bluegrass is the only native species referenced from here on out. The three forage kochia entries failed to establish likely due to herbicide residue remaining from the chlorsulfuron and sulfometuron methyl herbicide. Immigrant forage kochia successfully established on sites adjacent to plots in this study that were not treated with herbicide, which leads us to hypothesize the herbicide residue prevented establishment in this study.

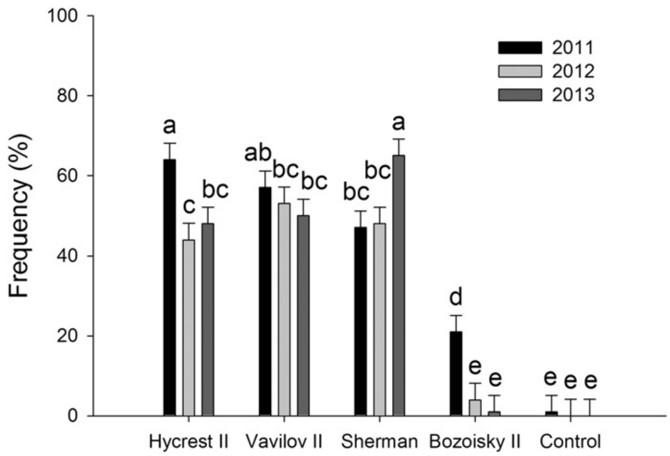

Figure 1. Frequency of seeded grasses the first 3 yr after seeding. Bars not labeled with the same letter differ ($P < 0.05$).

Starting Foliar Cover

There was no difference in foliar cover across plots before application of treatments ($P > 0.28$). Annual grasses consisted primarily of medusahead and downy brome. Annual grass cover averaged 47% ± 13.6% across plots. *Poa* species, consisting of *P. secunda* and *P. bulbosa,* were the next most abundant species and averaged 33 ± 11.8 % across plots. Forbs consisting of mustards, filaree, western salsify, prickly lettuce, and rush skeletonweed averaged 16% ± 4.1% across plots, collectively. Litter averaged 3% ± 2.4% across plots and bare ground 3% ± 1.0% across plots.

Frequency

There was a significant plant material by year interaction for frequency of Hycrest II, Sherman big bluegrass, and Bozoisky II ($P <$ 0.0001). Hycrest II had the greatest initial frequency at 64% ± 4.1% and decreased to 48% ± 4.1% by the third year of the study (Fig. 1). Jensen et al. (2009) reported Hycrest II frequency of 72%—85% across locations in UT, ID, MT, and ND with one location as low as 35%. Sherman big bluegrass frequency in yr 1 was 47% ± 4.1% and increased to 65% ± 4.1% in 2013 (see Fig. 1). Bozoisky II had the lowest frequency of seeded grasses at 21% ± 4.1%, and frequency decreased to 1% ± 4.1% in 2013. There were no grasses planted in the control plots, and very minimal native perennial bunchgrasses were present on the study sites, which led to a frequency of grasses in the control plots of < 1% ± 4.1% (see Fig. 1). Frequency of Vavilov II ranged from 57% ± 4.1% the first year of the study to 50% ± 4.1% in 2013.

There was a significant plant material by year interaction for frequency of weeds in the Bozoisky II plots ($P < 0.0001$). Weeds increased in the Bozoisky II plots from 58% ± 5.6% to 99% ± 5.6% between 2011 and 2013 (Fig. 2). The seeded grasses that established and persisted were able to keep the weed component reduced. Hycrest II, Vavilov II, and Sherman big bluegrass plots were similar in frequency of weeds and ranged from 43% ± 5.6% to 51% ± 5.6% over years.

There was a significant disturbance by year interaction for seeded grass frequency ($P = 0.008$) and a tendency for a disturbance by year interaction among frequency of weeds ($P = 0.055$). Seeded grass frequency was 15 ± 3.5 % greater on disturbed plots than undisturbed plots in 2011. However, by the end of the study, seeded grass frequency was similar between disturbed and undisturbed plots, with values of 35% ± 3.5% and 31% ± 3.5%, respectively. The lower frequency of grass establishment on the undisturbed plots resulted in a 14% ± 4.2% greater frequency of weeds than on the disturbed plots. However, by the end of the study, frequency of weeds was similar across undisturbed and disturbed plots, 71% ± 4.2% and 66% ± 4.2%, respectively.

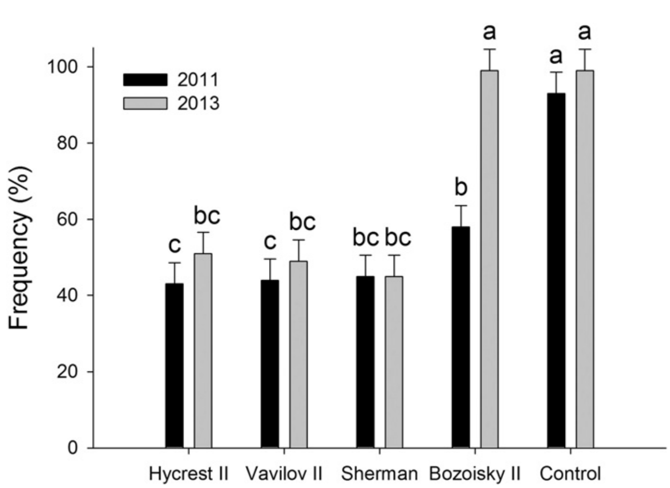

Figure 2. Frequency of weeds within plots for 2011 and 2013. Bars not labeled with the same letter differ ($P < 0.05$).

Biomass Production

Disturbance with the chisel plow and harrow before planting resulted in a disturbance by plant material interaction for biomass production ($P = 0.0004$). Biomass production was greater for seeded grasses on disturbed compared with undisturbed plots, 1074 ± 194 kg · ha^{-1} and 832 ± 194 kg · ha^{-1}, respectively. However, biomass production of the weeds was similar on disturbed and undisturbed plots, 797 ± 194 kg · ha^{-1} and 866 ± 194 kg · ha^{-1}, respectively.

There was a plant material by year interaction ($P = 0.003$; Table 2) for biomass production. Sherman big bluegrass and Vavilov II were similar in biomass production in 2012, 1940 ± 232 kg · ha^{-1} and 1797 ± 232 kg · ha^{-1}, respectively. Vavilov II biomass production decreased to 1229 kg · ha^{-1} in 2013. Bozoisky II had low establishment and was reflected in the low biomass production. Weed production was more than double in the control, and Bozoisky II plots compared with Hycrest II, Vavilov II, and Sherman big bluegrass plots. Weed production was similar among the Hycrest II, Vavilov II, and Sherman big bluegrass plots.

There was a plant material by month interaction ($P < 0.0001$; Table 3) for biomass production. Sherman big bluegrass matured earlier

Table 2
Biomass production (kg · ha^{-1}) of plant materials, seeded grass and weeds (± SE), for 2012 and 2013.

	---------------2012---------------		---------------2013---------------	
	Grass[1]	Weeds	Grass	Weeds
Control	0 ± 232 f	1254 ± 232 c	136 ± 232 e	1178 ± 232 c
Bozoisky II	105 ± 232 e	1481 ± 232 bc	139 ± 232 e	1301 ± 232 bc
Hycrest II	1455 ± 232 bc	562 ± 232 d	1181 ± 232 c	573 ± 232 d
Vavilov II	1797 ± 232 ab	429 ± 232 d	1229 ± 232 c	515 ± 232 d
Sherman	1940 ± 232 a	517 ± 232 d	1548 ± 232 abc	502 ± 232 d

[1] Means followed by different letters are significantly different ($P < 0.05$).

Table 3
Biomass production (kg · ha^{-1}) of plant materials, seeded grass and weeds (± SE), for May and July combined over 2012 and 2013.

	---------------May---------------		---------------July---------------	
	Grass[1]	Weeds	Grass	Weeds
Control	124 ± 232 f	1070 ± 232 cd	12 ± 232 g	1362 ± 232 bc
Bozoisky II	123 ± 232 f	1270 ± 232 bcd	120 ± 232 f	1512 ± 232 ab
Hycrest II	971 ± 232 d	552 ± 232 e	1665 ± 232 ab	584 ± 232 e
Vavilov II	977 ± 232 d	502 ± 232 e	2049 ± 232 a	443 ± 232 e
Sherman	1554 ± 232 ab	532 ± 232 e	1935 ± 232 a	487 ± 232 e

[1] Means followed by different letters are significantly different ($P < 0.05$).

in the season than the other seeded grasses, and biomass production was greater for Sherman big bluegrass in May. Hycrest II and Vavilov II were later maturing, exhibiting similar biomass production to Sherman big bluegrass at the July harvests. Weed production was greater in the control and Bozoisky II plots at both harvests.

Forage Quality

CP concentration had a significant plant material by month by year interaction ($P < 0.0001$) and was greater during the May harvest in the seeded grasses and weeds compared with the July harvest with the exception of Bozoisky II, which was similar in CP content at both harvests in 2013 (Fig. 3). The native bunchgrasses harvested in the control plot in May 2013 were similar in CP to the seeded grasses in May 2013; however, there was not enough native grass harvested at the other time points for comparison. CP content of the weeds was similar in the control plots at the May harvest in both years, but CP content of weeds within the Bozoisky II, Hycrest II, Vavilov II, and Sherman big bluegrass plots was greater in May 2012 compared with May 2013 (see Fig. 3).

There was a significant plant material by month by year interaction for NDF and IVTD content ($P < 0.0001$). Neutral detergent fiber content was greater in the spring for Sherman big bluegrass than the other seeded grasses (Fig. 4). The NDF content of the weeds was lowest at the harvest in May 2012 and continued to increase over the next three harvests. Sherman big bluegrass resulted in lower IVTD content in the May harvest of both years compared with the other seeded grasses. However, IVTD content was similar in all seeded grasses at the July harvest in both years. Digestibility was greater in the weed component of plots planted with Bozoisky II, Hycrest II, Vavilov II, and Sherman big bluegrass, at the first harvest, compared with the control plot (Fig. 5). Digestibility of the weed component was similar in the control plots at the May harvest of both years. Digestibility in the weeds component in the Bozoisky II, Hycrest II, Vavilov II, and Sherman big bluegrass plots decreased at the May harvest in 2013 compared with May 2012. Digestibility of the weed component was lower at the July harvests of both years compared with the May harvest, and all plots were similar in digestibility. Disturbance did not have an effect on CP, NDF, or IVTD content.

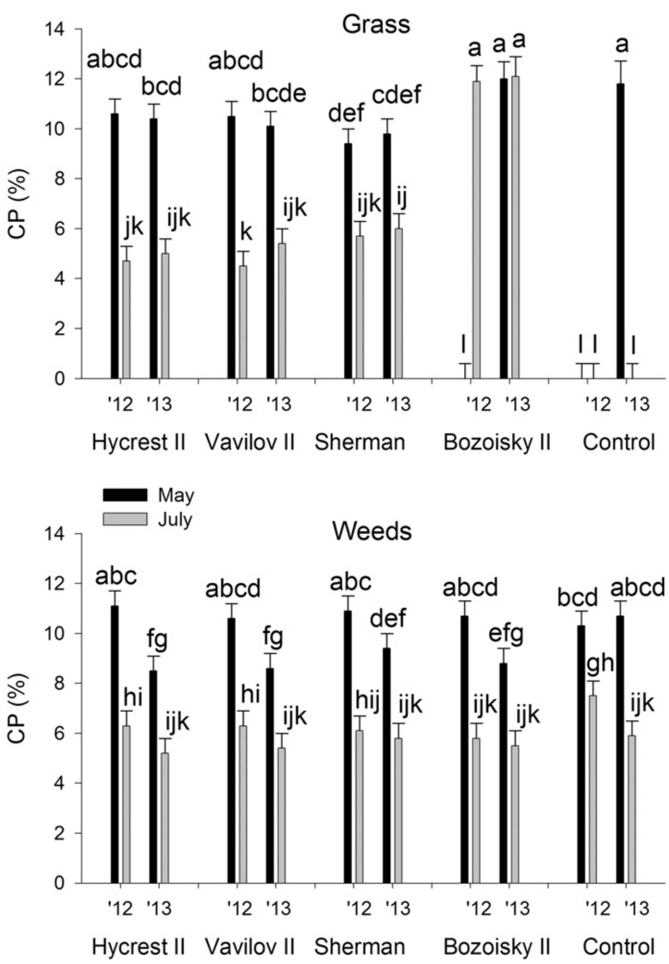

Figure 3. Crude protein (CP) of plant materials, seeded grasses and weeds, at the May and July harvests for 2012 and 2013. Bars not labeled with the same letter differ ($P < 0.05$).

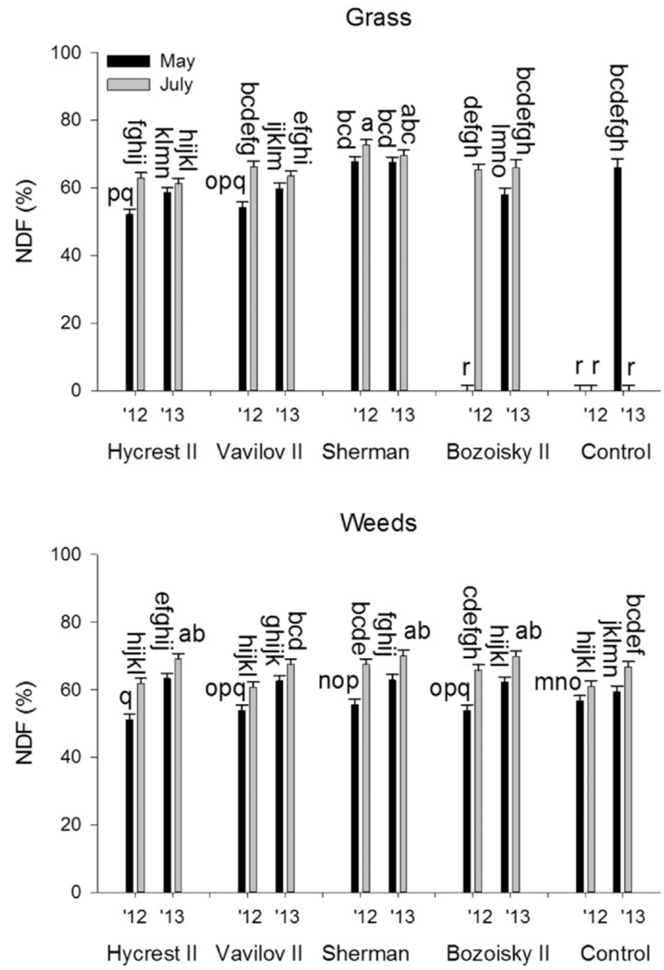

Figure 4. Neutral detergent fiber (NDF) of plant materials, seeded grasses and weeds, at the May and July harvests for 2012 and 2013. Bars not labeled with the same letter differ ($P < 0.05$).

Discussion

Native vegetation cover and biomass production decrease as medusahead density increases (Davies, 2011). The high weed biomass production in the control plots is an indicator that the current vegetation in the region is composed of medusahead and other undesirable weeds, and very few native bunchgrasses remain. An overlap in perennial bunchgrass and exotic annual grass spatial and temporal acquisition of resources (James et al., 2008) can help explain the decrease in perennial bunchgrasses. The increased fire frequency associated with increased exotic annual grasses (D'Antonio and Vitousek, 1992) also perpetuates the cycle of increased medusahead. Native plant communities that have evolved with less frequent fire frequencies are more susceptible to increased fires (Whisenant, 1990; Brooks et al., 2004).

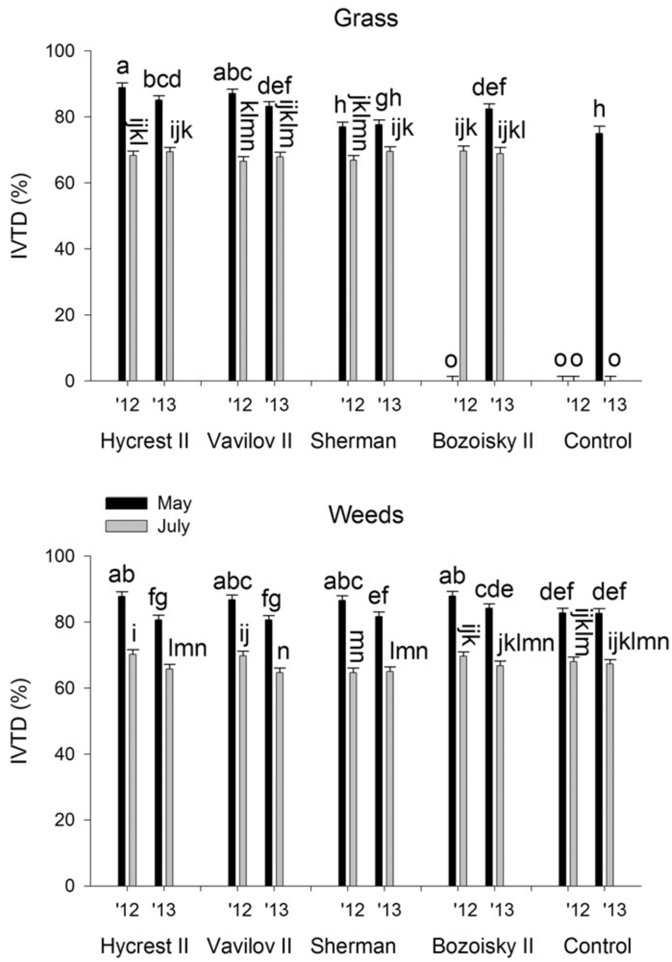

Figure 5. In vitro true dry matter digestibility (IVTD) of plant materials, seeded grasses and weeds, at the May and July harvests for 2012 and 2013. Bars not labeled with the same letter differ ($P < 0.05$).

The lack of native vegetation in this study is indicative of the aforementioned alteration and cycle of increased abundance of medusahead.

The introduced grasses, Hycrest II and Vavilov II, established on the harsh environment of the Channeled Scablands and persisted over the duration of the study. However, Bozoisky II failed to establish in this study. Russian wildrye can be difficult to establish (Ogle et al., 2012). Native grasses are relatively more difficult to establish and less persistent than nonnative grasses on sites with < 300 mm of annual precipitation (Asay et al., 2001; Robins et al., 2013). Precipitation was 9% below the long-term average during the establishment year (2011) in this study. However, Sherman big bluegrass was able to establish and persist over the duration of the study.

Biomass production of medusahead was lower in plots established with Hycrest II, Vavilov II, and Sherman big bluegrass. Increasing the abundance of perennial grasses can reduce the spread of weedy and invasive species (Blumenthal et al., 2003; Baker and Wilson, 2004). Davies (2008) reported a negative correlation between mature bunchgrass density and medusahead establishment. High densities of perennial bunchgrasses are necessary to reduce the invasion potential of exotic annual grasses (Davies et al., 2015). Initial grass establishment varied among Hycrest II, Vavilov II, and Sherman big bluegrass, and grass persistence continued to change among these species over the course of the study. In similar fashion, biomass production of these three grasses varied. Bunchgrasses that produce high biomass yields contribute to invasion resistance (James et al., 2008). Increasing perennial bunchgrass density and thus providing competition with exotic annual grasses from desirable species is necessary to provide a plant community that is resistant to reinvasion (Borman et al., 1991; Davies, 2008). Biomass production of Hycrest II, Vavilov II, and Sherman big bluegrass remained at a level that suppressed medusahead and other weed production.

Invasive annual grasses can quickly recolonize an area that has been treated and prepared for revegetation because of abundant seed production and/or persistent seed banks (Young, 1992; Humphrey and Schupp, 2001). Control methods to remove medusahead provide only short-term control, and if revegetation is not successful, medusahead rapidly reestablishes (Monaco et al., 2005; Sheley et al., 2007; Davies, 2010). The inability of Bozoisky II to establish provided an opportunity for medusahead and other weeds to flourish. This was demonstrated by the increased weed production in the Bozoisky II plots during the first three harvests compared with the control plots. Establishment of grass cover is necessary to control weeds and reduce the reestablishment of medusahead (Monaco et al., 2005).

Annual grasses, such as *B. tectorum* and *T. caput-medusae,* germinate in the fall and elongate roots during low winter temperatures (Harris and Wilson, 1970). This rapid root elongation gives them an advantage over native grass species such as bluebunch wheatgrass due to their ability to use available soil moisture earlier in the season. However, crested wheatgrass roots are able to penetrate the soil almost as rapidly as the annual grasses and make it to favorable soil moisture (Harris and Wilson, 1970). Davies et al. (2010) was able to limit the establishment of medusahead by seeding crested wheatgrass. The establishment of Hycrest II and Vavilov II in this study reduced medusahead and other undesirable weed abundance.

The arid environment and highly erodible soil provide additional obstacles that make the Channeled Scablands a difficult area to revegetate. Moisture availability in arid environments can be a key determinant in the success of revegetation (Bleak et al., 1965; Robins et al., 2013). The likelihood of successful revegetation decreases with high density of medusahead and after substantial losses of native plant species (Davies, 2011; Davies and Sheley, 2011). Success of a revegetation process can be enhanced with inclusion of species that are adapted to the environmental conditions of the site being revegetated. Hycrest II, Vavilov II, and Sherman big bluegrass were all successful in establishing and persisting throughout the study in the harsh environment of the Channeled Scablands. In highly degraded ecosystems, rehabilitation with improved species that will establish and compete with undesirable annuals is necessary. The success of ecological restoration ultimately depends on the creation of self-sustaining ecosystems (McAlpine et al., 2016). Temporal and spatial aspects of restoration are important for both plants and animals, such that sustainable management strategies aimed at when and where restored rangelands are grazed will be key for achieving long-term effective outcomes.

Initial establishment of seeded grasses was 15% greater with mechanical disturbance compared with the undisturbed plots, but this difference dissipated by the end of the study. Medusahead and other weeds were 14% greater on the undisturbed plots at the start of the study but were similar by the end of the study. Biomass production of seeded grasses was greater due to the mechanical disturbance, but the added benefit from disturbance did not persist over the years. Providing extra disturbance may be beneficial for the initial establishment of grasses, but the extra costs associated may not be warranted when herbicides are used to control vegetation before planting.

Sherman big bluegrass matured earlier in the season than the other seeded grasses; thus, NDF content was greater and IVTD content was lower in the spring for Sherman big bluegrass than the other seeded grasses. The NDF content in Sherman big bluegrass remained higher than the other seeded grasses during the July harvest; however, IVTD content was similar among seeded grasses at the July harvest. Hycrest II and Vavilov II remained green late into the season, thus providing a green forage alternative to medusahead later in the season. The seeded grasses in this study were low in CP content late in the season, but the increased forage production from the seeded grasses will provide an alternative forage to medusahead for livestock late in the season.

Implications

Producers and land managers in the Channeled Scablands of eastern Washington are faced with a daunting task of revegetating the exotic annual grass-invaded rangelands. Hycrest II crested wheatgrass, Vavilov II Siberian wheatgrass, and the native Sherman big bluegrass all established and persisted over the course of the study, thus providing a plant source that producers can use to compete with medusahead. Providing adequate forage supply, which occurred from the increased biomass production from these three species, may supply ample forage to sustain livestock. Long-term monitoring needs to be conducted to determine if these grass species will persist and continue to compete with medusahead. Grazing studies need to be conducted to determine if these grass species will persist long term after livestock usage and if they will provide an alternative forage to lupine during the critical period of gestation to help reduce the incidence of CCS.

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