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Effects of Cheatgrass Control on Wyoming Big Sagebrush in Southeastern Utah

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EFFECTS OF CHEATGRASS CONTROL ON WYOMING BIG SAGEBRUSH IN SOUTHEASTERN UTAH

by

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GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

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This thesis has been read by each member of the following graduate committee and by majority vote has been found to satisfactory.

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BRIGHAM YOUNG UNIVERSTITY

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ABSTRACT

EFFECTS OF CHEATGRASS CONTROL ON WYOMING BIG SAGEBRUSH IN SOUTHEASTERN UTAH

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Critical mule deer (*Odocoileus hemionus*) winter ranges in southeastern Utah dominated by Wyoming big sagebrush (*Artemisia tridentata* var. *wyomingensis* [Beetle and A. Young] Welsh) have developed dense cheatgrass (*Bromus tectorum* L.) understories. These communities are currently characterized by predominately mature to decadent stands of sagebrush with few perennial grasses and forbs. Sagebrush seedlings and perennial grasses compete for limited resources with annual grasses and forbs. To determine the affects of cheatgrass control on sagebrush growth and reproductive characteristics, imazapic (PLATEAU®, AC 263,222) herbicide was sprayed at 438.5 ml/ha with water and methylated seed oil during active fall growth of cheatgrass in 2002. Sagebrush growth and reproductive variables were measured on browsed and unbrowsed (caged) plants on sprayed and non-sprayed paired plots on 6 sites. Cheatgrass and other annual forb pretreatment cover was reduced from 23% to less than 3% the first year after the herbicide treatement and only increased to 4% the second year. Soil moisture on the treated plots was available at 15, 30, and 60 cm for several days to several weeks longer than on the control plots depending on the depth in the soil and year. Annual leader growth and flowering seedstalk length were similar on unbrowsed and browsed shrubs, but the number of seedstalks per plant was decreased by browsing. The number of sagebrush flowering seedstalks was significantly reduced by the herbicide the first year after the treatment, but recovered by the second year. The decrease in flowering seedstalks per sagebrush reduced the number of sagebrush seedlings observed the second year after the treatment (control = 81,800 seedlings/ha and treated = 16,700 seedlings/ha). Both seedstalk length (treated = 13.4 cm and control = 11.2 cm) and annual leader growth (treated = 6.2 cm and control = 5.3 cm) were greater on treated plots than control plots. Overall, imazapic can provide a window of cheatgrass and annual forb control to allow big sagebrush seedlings and perennial grasses and forbs to establish.

Keywords: *Artemisia tridentata wyomingensis*, imazapic, *Bromus tectorum*

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INTRODUCTION

Winter is a survival season for mule deer (*Odocoileus hemionus*). All activities and behavior are a balance between energy intake and expenditure (Updike et al. 1990). Wyoming big sagebrush (*Artemisia tridentata* Nutt. var. *wyomingensis*) (Beetle and A. Young) communities are a critical component of mule deer winter habitat (Pederson and Welch 1982). Wyoming big sagebrush provides necessary nutrition during fall, winter, and spring when herbaceous vegetation becomes scarce (Wambolt 1996; Welch 2004). Mule deer require 10-12% crude protein for maintenance during the winter. Sagebrush maintains a high nutritive value of 12% crude protein during winter months while the crude protein of other shrubs such as antelope bitterbrush (*Purshia tridentata* Pursh) and true mountain mahogany (*Cercocarpus montanus* Raf.) drops to 7-8% (Welch 2005).

Wyoming big sagebrush communities have been reduced or eliminated through a number of scenarios mostly associated with cheatgrass (*Bromus tectorum* L.), an invasive alien annual species. Big sagebrush is not fire tolerant, while cheatgrass populations rebound after fire (Warg 1938; Billings 1952; Pellent 1990). Fire intervals for sagebrush-steppe communities average 60-100 years, while those for the more xeric Wyoming big sagebrush may average every 100 years (Whisenant 1990). When cheatgrass creates continuous fine fuel in the understory, fire intervals are shortened and eventually may burn every 3-5 years (Whisenant 1990). Big sagebrush is eventually extirpated with high fire frequencies.

Competition from cheatgrass preempts resources prior to native grass, forb, and shrub, especially big sagebrush seedlings, initiation of spring growth (Klemmedson and Smith 1964; Young and Evans 1989; Hall et al. 1999; Williams et al. 2002). Wyoming big sagebrush reproduces sporadically and requires late season precipitation for emergence (Meyer 1994), creating episodic recruitment events. With a limited window of opportunity to establish and competition from cheatgrass, sagebrush seedling survival is severely reduced (Young and Evans 1989; Wagstaff and Welch 1990; Meyer 1994). Limited recruitment from young sagebrush will eventually produce a predominately mature to decadent stand of sagebrush that will eventually die due to old age, even in the absence of fire (Davis et al. 2006).

Heavy fall and spring browsing on over 50% of the annual stems in consecutive years can stress big sagebrush and reduce the number of seedstalks per plant (Cook and Stoddart 1963; Cook and Child 1971; Trilca and Cook 1971; Wagstaff and Welch 1990). Big sagebrush stores over half of its nonstructural carbohydrate reserves in its leaves and first year's growth (Bilbrough and Richards 1993; Hoffman and Wambolt 1996). Heavy browsing year after year reduces seedstalk production and lack of recruitment eventually results in a stand with high mortality or shrubs of predominantly decadent age class. Both scenarios can eventually result in the demise of a big sagebrush stand. Other factors that can influence shrub die-off include drought, disease, and winter injury. A combination of any of these factors can further stress Wyoming big sagebrush.

Methods have been developed to reduce annual species like cheatgrass. Control by mechanical (Davis and Harper 1990), chemical (Young and Evans 1971; Evans and Young 1977; Ogg 1994; Whitson and Koch 1998), prescribed fire (Rasmussen 1994), and biological means (Johnson et al. 1993; Vallentine and Stevens 1994) followed by seeding (Evans and Young 1978; Buman et al. 1988; Monsen and Turnipseed 1990) reduces cheatgrass. It typically reduces the existing sagebrush population as well. Few treatments are able to reduce cheatgrass while maintaining sagebrush populations for wintering mule deer. Selective herbicides, such as imazapic (PLATEAU®, AC 263,222, BASF 2002) can reduce several annual grasses and forbs, with limited negative effects on perennial grasses, forbs, and shrubs (Master et al. 1996; Washburn and Barnes 2000; Shinn and Thill 2004). The objective of this study is to determine the affects of chemical (imazapic) control of cheatgrass and other annuals on sagebrush flowering seedstalk production, seedling establishment, annual growth, and vigor.

METHODS

Study Areas

The study was located on land owned by the State of Utah in San Juan County, just south of Blanding Utah. The state lands are single square mile sections that are surrounded by land managed by the Bureau of Land Management (BLM). Seven blocks were established on critical winter habitat for mule deer that summer on Elk Ridge. The elevation ranges from 1,645 m to 1,753 m and topography is nearly flat. Three blocks were located on Black Mesa, which include Black Mesa A (lat 37°31'37"N, long -109°33'54"W), Black Mesa B (lat 37°31'2"N, long -109°34'42"W), and Black Mesa C (lat 37°30'20"N, long -109°34'47"W). Other blocks were located on Cave Canyon (lat 37°31'17"N, long -109°18'36"W), Alkali Canyon (lat 37°30'46"N, long -109°21'18"W), Mustang Mesa (lat 37°33'56"N, long -109°23'23"W), and Murphy Point (lat 37°31'9"N, long -109°28'16"W).

Black Mesa B, C, Cave Canyon, and Mustang Mesa have soils classified as part of the Ruinpoint series and are a fine-silty, mixed, superactive, mesic Ustic Haplocambids. Black Mesa A borders on the Ruinpoint and Rizno soil series. The Rizno soil series is a loamy, mixed, superactive, calcareous, mesic Lithic Ustic Torriorthents. Alkali Canyon has soil classified as part of the Littlenan soil series and is a fine, smectitic, mesic Ustertic Haplocambids. Murphy Point soil has not yet been classified. They all formed from eolian material and alluvium derived from sandstone, except the Littlenan series, which is from alluvium and residuum derived dominantly from shale. Soils are moderately deep and well drained with little to no rock in the profile (USDA and NRCS 2006). All sites have a sandy loam soil texture.

Experimental Design

The experimental design was a randomized complete block design. Within each treatment main plot a subplot of unbrowsed and browsed sagebrush was established by caging or leaving uncaged 5 healthy Wyoming big sagebrush plants. Each of the 7 blocks contained a control plot and a treated plot measuring 27.4 m by 30.5 m. On 22 October 2002, during active growth of fall-germinated cheatgrass and winter annual forbs, imazapic herbicide mixed with methylated seed oil was applied at a rate of 438.5 ml/ha to the treated plot. The herbicide was applied with a 9 m boom sprayer attached to a tractor.

Seeding

Wyoming big sagebrush and needle-and-thread grass (*Stipa comata* Trin. and Rupr.) were seeded using hand seeders. Wyoming big sagebrush was seeded at a rate of 9.6 kg/ha with 7% pure live seed (PLS). Needle-and-thread was applied at 1.35 kg/ha with 90% PLS. Seeding was completed on 26 November 2002. No seedbed preparation was completed following seeding, because sagebrush is best sown on the soil surface or on top of snow (Meyer 1994).

Vegetation Sampling

Vegetation data were collected before the herbicide treatment in the fall of 2002, post treatment in fall of 2003, and spring 2004 and 2005. Each plot had a permanently marked 30 m baseline with 3, 15 m belt transects running perpendicular to the baseline on randomly selected numbers. Ten 0.25 m^2 quadrats were placed every 1.5 m on the belt transects. Ocular cover and nested frequency data were collected in each quadrat for individual plant species, total vegetation, litter, rock, pavement, cyptograms, and bareground.

Cover data were collected by species using a modified Daubemire (1959) cover class method (Bailey and Poulton 1968). The seven cover classes in the quadrat were 1) 0.1-1.0%, 2) 1.1-5.0%, 3) 5.1-25.0%, 4) 25.1-50.0%, 5) 50.1-75.0%, 6) 75.1-95.0%, and 7) 95.1-100.0%. To determine percent cover, the midpoint of each cover class was summed and divided by 30 quadrats per plot.

Nested frequency data were collected by dividing each quadrat into 5 sequentially larger areas. Each species received a score ranging from 1-5. The frequency score is recorded by locating the smallest area that the species is rooted in. A score of 5 = 1% of the quadrat area, 4 = 5%, 3 = 25%, 2 = 50%, and 1 = the remainder of the quadrat area. The highest possible score a species or cover type can receive per quadrat is 5 and 50 for each belt transect. Higher nested frequency scores represent higher abundance and distribution for that species. Nested frequency data were used instead of density, because of the difficulty in obtaining accurate density counts when the understory is dominated by small and numerous annual species (Smith et al. 1986).

Shrub densities were estimated using 3, 0.002 ha strips. The strip area measured 1.34 m by 15 m and was centered over each 15 m belt transect. All shrubs rooted within each strip were counted, given an age class, a vigor rating, and a utilization rating according to the Cole Browse method (Cole 1963). Height-crown measurements were recorded every 3 m on the belt for the closest mature shrub.

Annual leader growth, the number of flowering seedstalks, and the length of each flowering seedstalk were measured for each of the paired caged and uncaged sagebrush plants. Annual leader growth and seedstalk length of 5 randomly selected leaders and seedstalks were measured and the total number of seedstalks counted for each plant.

Soil Moisture and Precipitation Sampling

Soil water potential data were collected using Delmhorst, Inc GB-1 gypsum soil moisture blocks. Gypsum block resistances were recorded using a Delmhorst, Inc KS-D1 meter. The control and treated plots each contained 9 gypsum blocks buried at depths of 15, 30, and 60 cm in 3 locations within the plot. Blocks were read at least monthly and twice per month during critical growth periods for cheatgrass.

Annual precipitation data were collected in a rain gauge made of 15.2 cm wide PVC pipe buried at 0.6 m in the ground and extending 0.3 m above the ground. The tops of the rain gauges were covered with 0.64 cm hardware cloth to prevent debris or animals from entering the tube. Rain gauges were drained and recharged with antifreeze, transmission fluid, and water each fall and spring. The rain gauges were measured each time the soil moisture blocks were read.

A soil sample was collected to determine the physical and chemical properties of the soil for each block. The soil samples were sent to Brigham Young University Soil

Analysis lab for soil tests. The soil tests included: pH (Rhodes 1982), percent sand, silt, and clay (Day 1965), phosphorus availability (Olsen et al. 1954), potassium availability (Schoenau and Karamonos 1993), percent organic matter, and electrical conductivity of the saturation extract.

Statistical Analysis

Mixed model analysis (Littell et al. 1996) was used to analyze the data with year as a repeated measure. Blocks were considered random with the treatments considered fixed. Means were separated by Tukey's honest significant multiple comparison procedure. Significant differences were recorded at an alpha of 0.05. Data were transformed ($\log_{10} + 1$, square root) to normalize where appropriate. Only 6 blocks were analyzed. The Mustang Mesa block was omitted, because cover and nested frequency from the pretreatment control and treated-plot data were significantly different from each other.

RESULTS

Precipitation and Soil Moisture

Below-average precipitation in the fall of 2002 and spring of 2003 did not support establishment of seeded species or cheatgrass growth after treatment application. Annual precipitation in Blanding, Utah averaged 334 mm the last 23 years (Fig. 1). Annual precipitation from rain gauges on each site averaged 231 mm in 2003 and 226 in 2004, but doubled in 2005 to 430 mm (Fig. 2). Below-average precipitation may have extended the ability of the herbicide to suppress cheatgrass in 2003 and 2004. Soil moisture on the treated plots was available at 15, 30, and 60 cm for several days to several weeks longer than on the control plots depending on soil depth and year (Figs. 3 and 4). At 30 cm deep in 2003, soil moisture was extended by 28 days longer on the treated than control plots. By 2004, cheatgrass and annual forbs began to invade the treated plots and soil moisture was only extended for an additional 11 days.

Herbaceous Understory

Cheatgrass, storksbill (*Erodium cicutarium* L.), and *Astragulus nuttallianus* var. *micranthiformis* A. DC. were the dominant annual species in the herbaceous understory. The combined nested frequency of these 3 species was significantly ($P < 0.05$) lower on the treated than control plots. Pretreatment (2002) annual plant cover averaged 23% and decreased significantly ($P < 0.05$) to 3% in 2003 and 4% in 2004. Mean annual plant cover on the control plots averaged lower in 2003 and 2004 due to below-average precipitation (Fig. 5). Precipitation nearly doubled in 2005 from the 2 previous years (Fig. 2) and annual species cover increased on both the control and treated plots. The control plots increased from 10% cover in 2004 to 30% in 2005 and the treated plots increased from 4% to 17% (Fig. 5).

Cover and nested frequency of perennial grasses were similar during the course of the study for both treated and control plots. However, perennial grasses and forbs were few and cover was never higher than 3% for all perennial grass species combined (Fig. 6). Needle-and-thread grass was seeded in November of 2002 and was never observed during all sampling years.

Wyoming Big Sagebrush

Mature sagebrush density during pretreatment estimates averaged almost 8,000 plants/ha on both the control and treated plots. Density remained fairly constant on the control plot until 2005 when it decreased significantly ($P < 0.05$) to 6,400 plants/ha.

Density on the treated plots decreased from 2002 to 2004, but in 2005 also averaged 6,400 plants/ha (Table 1). No differences in sagebrush density were found between the treated and the control plots. Decreases in density from 2002 to 2005 were most likely a result of drought conditions in 2003 and 2004 (Fig. 2). Decadence (25% of crown dead) during pretreatment (2002) was fairly high at 33% on the control and 41% on the treated plots. Decadence increased in 2003 to 68% of plants on the control and 74% on the treated plots. With over half the population displaying decadence on both plots, decreases in density were not attributed to the treatment.

Canopy cover in 2002 (pretreatment) was estimated at 12% on both the control and treated plots. From 2003 to 2004, cover on the treated plots increased significantly ($P < 0.05$) from 10% to 13%, while no significant difference was observed on the control plot (Fig. 6). No difference was observed in 2005 between all treatments. The height and crown of sagebrush for both treatments averaged 64 cm by 80 cm prior to treatment in 2002. The height on the control plots decreased by 8 cm in 2003 and 2004 from pretreatment measurements, while the treated plots had no significant difference ($P < 0.05$). Both the treated and control plots increased in height significantly ($P < 0.05$) in 2005 (Table 2) with above average precipitation (Fig. 2).

The first year after the herbicide treatment, the treated plots averaged 34 flowering seedstalks per sagebrush. This was significantly ($P < 0.05$) lower than the control plots, which averaged 90 seedstalks per sagebrush (Fig. 7). By the second year there was no difference between the control and the treated plots. The length of the seedstalks and annual leader growth were both significantly ($P < 0.05$) longer on the treated plots (Table 2).

In April of 2004, precipitation was 90% above normal (Fig. 1) and sagebrush seedling density averaged 81,800 seedlings/ha on the control and only 16,700 seedlings/ha on the treated plots. This was the only year during the course of this study that seedlings were observed. In 2005, a few young sagebrush plants were found, but only on the control plot of Alkali Canyon. The reduction of flowering seedstalks the previous spring due to the herbicide application would account for the reduced number of seedlings observed on the treated plots.

The sagebrush seedlings observed in 2004 were most likely from natural dispersal rather than from the November 2002 seeding. Sagebrush seeds typically only survive for one or two growing season (Young and Evans 1989) and seedlings in 2004 would have been 2 growing seasons from the seeded date. Sagebrush seeds typically fall within 1-3 meters of the mother plant (Wagstaff and Welch 1990). Seedlings were observed predominately underneath the sagebrush canopy and not uniformly distributed like might have been expected from artificial seeding.

Utilization was light to moderate in 2003 and 2004, but increased in 2005 to moderate. The first 2 years of the study were during drought conditions, which may have allowed deer to stay higher on the mountain. Above normal precipitation in the winter of 2004-2005 forced deer in lower regions of the winter ranges. Few differences were observed between the sagebrush plants that were protected from browsing and those left unprotected. Both annual leader growth and flowering seedstalk length on sagebrush displayed no difference between protected and unprotected big sagebrush plants (Table 2). The only difference was the number of flowering seedstalks per sagebrush, which were significantly ($P < 0.05$) greater on plants protected from browsing than those left unprotected (Table 2). Sagebrush seedstalks are produced on top of the plant and would be one of the first parts of the sagebrush to be utilized from browsing (Wambolt and Hoffman 2004).

DISCUSSION

Imazapic herbicide reduced cheatgrass cover and nested frequency, while maintaining a mature stand of sagebrush. Cheatgrass and annual forb cover was held to less than 4% for 2 years and then increased to 17% the third year. Plot sizes were small (27.4 m by 30.5 m) and a large seed source near the edge of the plots allowed for cheatgrass reestablishment. The increase in cheatgrass may not have been so dramatic if a larger area had been treated. Cheatgrass was never completely eliminated underneath the sagebrush canopy by the treatment, but may have been further reduced with a smaller droplet size with increased pressure. The sagebrush canopy was an obstacle for the herbicide penetrating to the herbaceous understory. A smaller droplet at a higher pressure would have forced more droplets through the shrub canopy to reach the herbaceous understory. Dense litter cover underneath the sagebrush canopy may have also tied up the herbicide from reaching the herbaceous understory.

It was originally hypothesized that seedling production would be greater on the treated plots; in response to a longer period of soil moisture availability as a result of less soil water used by annuals. According to Monson and Meyer (1990), timing of precipitation is also an important factor for Wyoming big sagebrush emergence. A single late winter snowfall will increase seedling emergence, while drought is a principle cause of sagebrush seedling mortality (Meyer 1994). Although soil moisture was available longer on treated plots for 2 years, seedlings were only observed the second year and the control plots had almost 5 times more seedlings per hectare than the treated plots. Flowering seedstalks the previous year had been reduced by the herbicide application, which would have decreased the number of seeds from nurse plants that fell to the ground on the treated plots. April precipitation in 2004 was twice the 23 year mean (Fig. 1) and provided the necessary late season precipitation needed for Wyoming big sagebrush seedling emergence.

The low precipitation in the spring of 2003 may partially explain why the artificial seeding of Wyoming big sagebrush and needle-and-thread were never observed. Both species are considered tolerant of imazapic as mature plants, but limited information is known about their tolerance as seeds and seedling. A species tolerance may vary by its growth stage and its genotype (Norcini et al. 2003).

Very few seedlings from 2004 survived to 2005. Cheatgrass and the annual forbs had increased to 17% on the treated plot and 31% on the control. Hall et al. (1999) showed that bitterbrush seedling emergence was negatively correlated with the number of annual plants/m^2. Big sagebrush seedlings would display similar results with competition from annual plants.

Reducing annual species was expected to mainly affect sagebrush seedlings and juveniles with little to no affect on mature plants. Mature plants have larger roots systems and can accumulate resources deeper and broader (Cline et al. 1977). Mature sagebrush plants were also observed benefiting from the reduced competition and increased time of soil moisture availability. Annual leader growth and flowering seedstalk length were both longer on the treated plots. Canopy cover of sagebrush also increased on the treated plot from 2003 to 2004.

By 2005, cheatgrass had reinvaded the treated plots leaving no difference in cheatgrass cover or nested frequency from pretreatment values in 2002. Valuable species that can compete with cheatgrass and annuals forbs need to be seeded on the plots, especially when very little residual grasses and forbs are present. Creating safe sites for seeds is difficult without some type of soil disturbance. Safe sites can be created by drilling perennial grasses and forbs with a rangeland or Truax drill. Drilling would place each seeded species at the optimal depth for germination and emergence. Seeded species would fill the disturbed areas left vacant from cheatgrass removal and help prevent cheatgrass from reinvading the area.

Further research needs to be done on a larger scale to determine if cheatgrass can be kept under control for several years to allow perennial grasses and forbs to firmly establish and increase. Further work also needs to be done to see if Wyoming big sagebrush seedlings can benefit from reduced cheatgrass competition in subsequent years after spraying. Overall, imazapic can provide a window of opportunity to allow sagebrush seedlings and perennial grasses and forbs to establish with normal precipitation. Perennial grasses and shrubs can keep cheatgrass and other annuals species under control (Asay and Knowles 1985; Buman et al. 1988; Monsen and Turnipseed 1990; Whitson and Koch 1998) thereby decreasing the loss Wyoming big sagebrush which is critical for mule deer winter habitat.

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Table 1. Wyoming big sagebrush density, size, and cover before (2002) and after (2003) application of Plateau herbicide in the fall of 2002 in San Juan County, Utah.

	Treatment	Density[1] (Plants/ha)	Height (cm)	Crown Width (cm)	Line Intercept Cover (%)
2002	Herbicide	8125 cd	64 bcd	80.1 ab	11.7 ab
	Control	7828 bd	65.4 bc	81.7 ab	11.8 ab
2003	Herbicide	7565 b-d	59.5 cd	75.0 a	10.1 a
	Control	8020 bd	57.6 ac	80.3 ab	10.4 ab
2004	Herbicide	7402 b-d	60.7 cd	76.2 a	13.2 b
	Control	7689 bd	57.6 ac	74.8 ab	12.1 ab
2005	Herbicide	6453 ab	68.3 cd	93.0 b	12.1 ab
	Control	6419 ac	66.2 ac	90.8 ab	12.3 ab

Within each column and across years, means with different letters are significantly different using Tukey's honestly significant difference multiple comparison procedure ($P < 0.05$).

[1] Square root transformation used for analysis.

Table 2. Wyoming big sagebrush growth characteristics after 2002 fall application of Plateau herbicide in San Juan County, Utah.

Treatment	Flowering Seedstalk Length (cm)	Annual Leader Growth (cm)[1]	Flowering Seedstalks/plant[1]
Herbicide	13.4 b	6.2 b	113 a
Control	11.2 a	5.3 a	82 a
Caged	12.7 a	5.8 a	127 b
Uncaged	11.9 a	5.7 a	73 a

Within each column and treatment, means with different letters are significantly different using Tukey's honestly significant difference multiple comparison procedure ($P < 0.05$).

[1] Log transformation used for analysis.

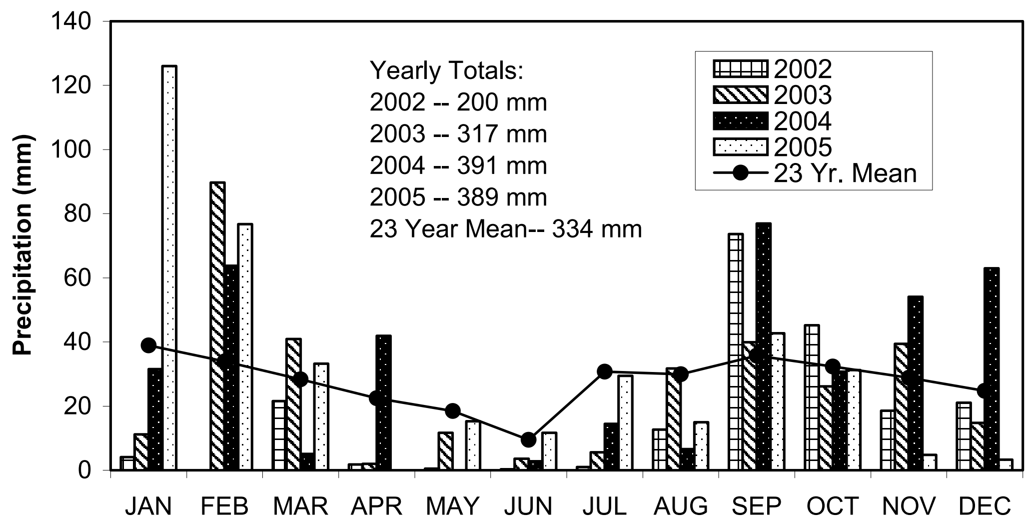

Figure 1. Monthly precipitation in Blanding, Utah from 2002 to 2005 (Utah Climate Summaries 2006).

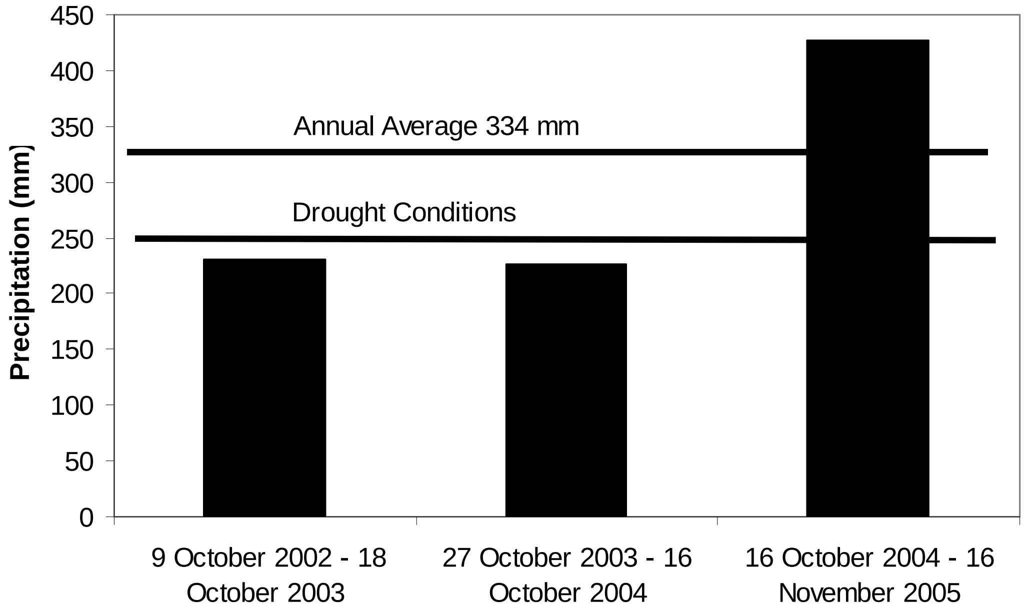

Figure 2. Annual precipitation from rain gauges located on southern Utah study sites. The extra 30 days in 2005 added very little to overall precipitation (5 mm in Blanding, Utah). Drought conditions are 25% below normal, which is 250 mm for Blanding, Utah.

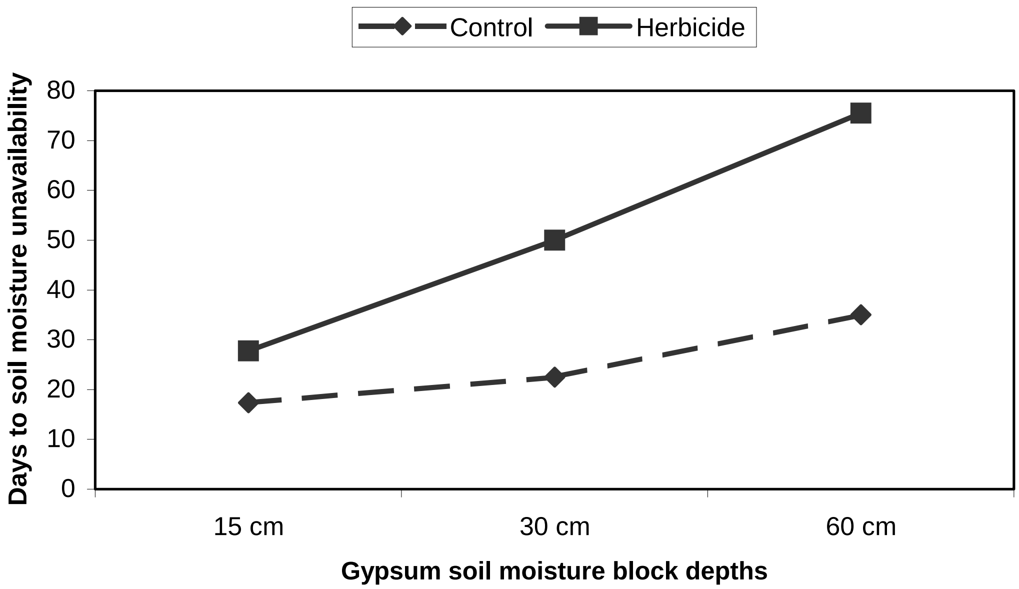

Figure 3. Number of days from 30 April 2003 to soil moisture unavailability (matric potential < -1.5 MPa).

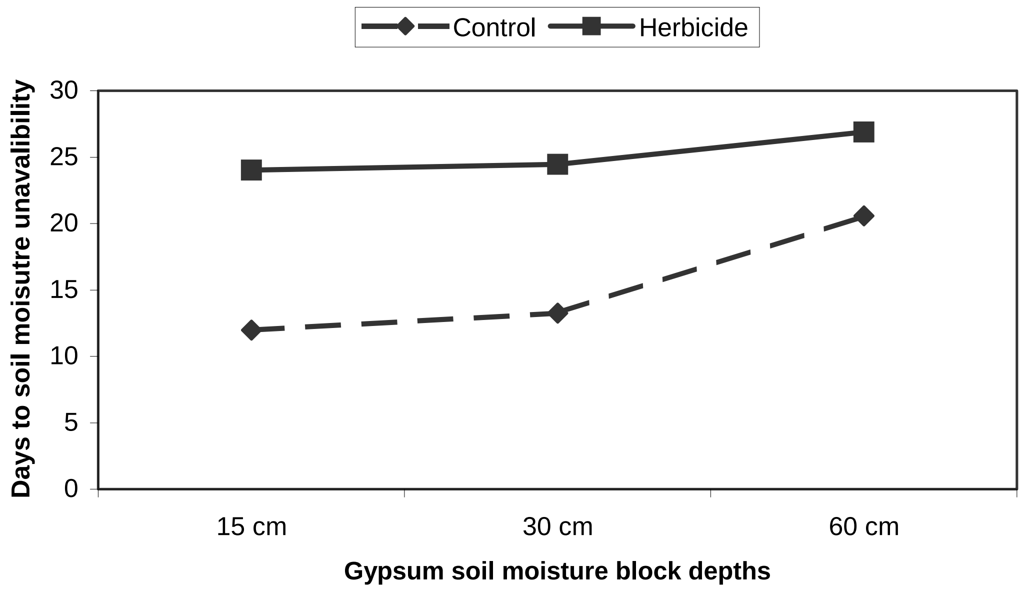

Figure 4. Number of days from 27 March 2004 to soil moisture unavailability (matric potential < -1.5 MPa).

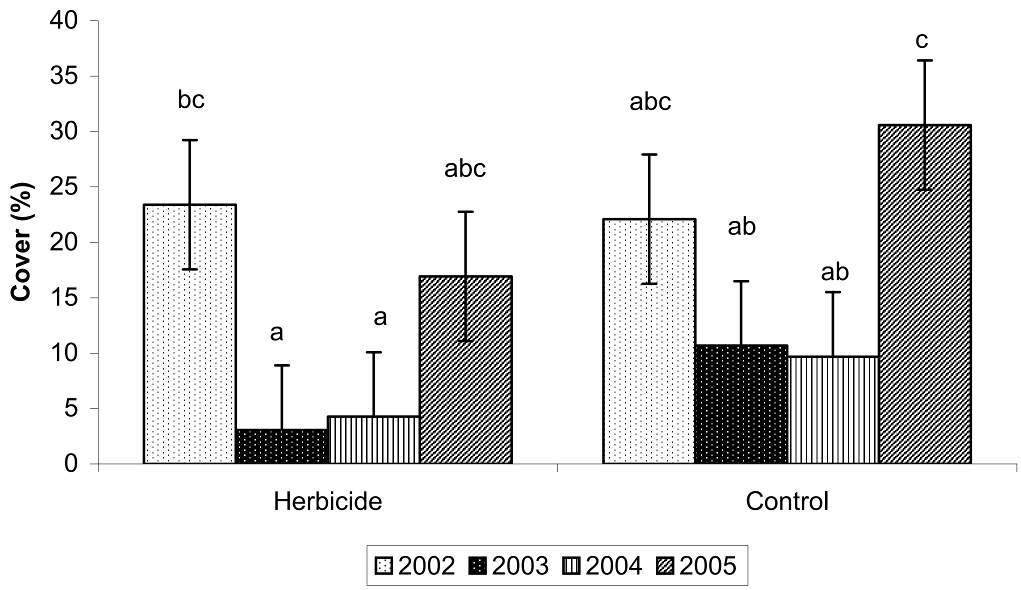

Figure 5. Annual species (*Bromus tectorum*, *Erodium cicutarium*, and *Astragulus nuttallianus*) percent canopy cover for Plateau herbicide-treated and control treatments. Data in 2002 is pretreatment for both control and treated plots. Plateau herbicide was applied in fall of 2002. Different letters indicate a significant difference among treatments within and across years ($P < 0.05$).

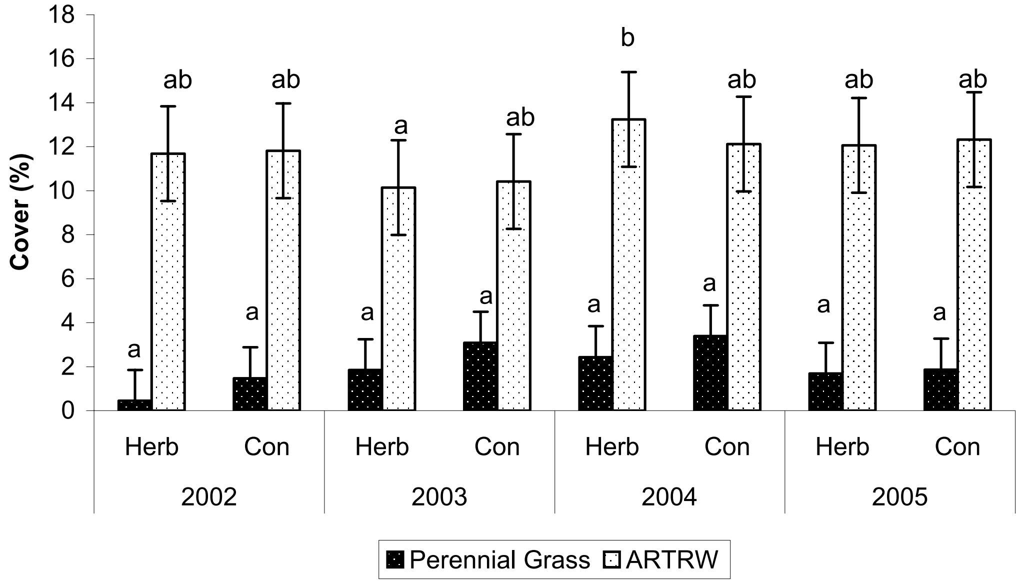

Figure 6. Percent canopy cover for perennial grasses and Wyoming big sagebrush (ARTRW). Data in 2002 is pretreatment for both control and treated plots. Plateau herbicide was applied in fall of 2002. Different letters indicate a significant difference among treatments within and across years ($P < 0.05$).

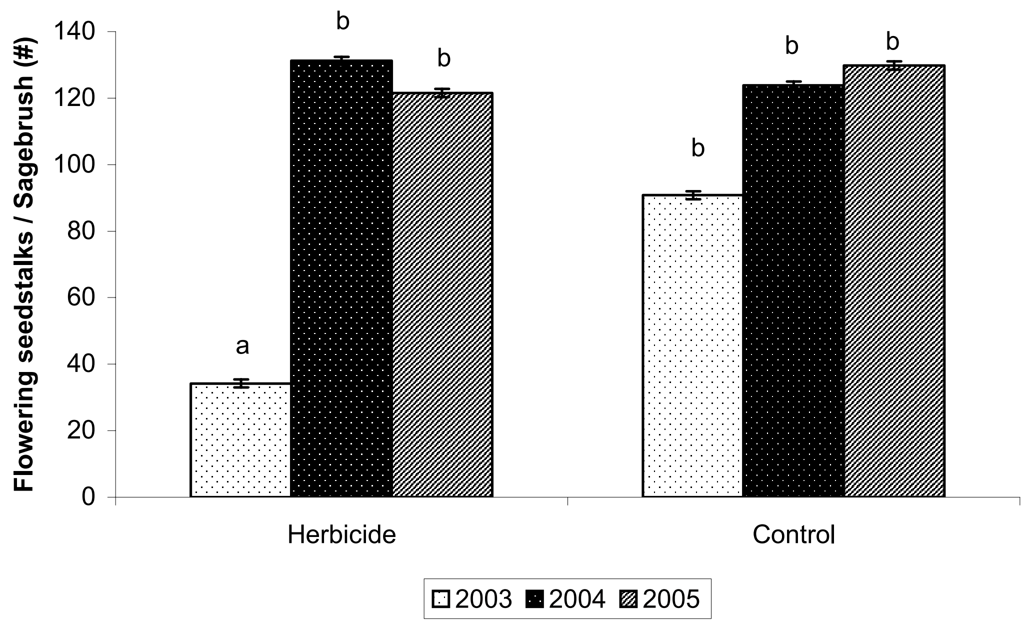

Figure 7. Average number of flowering seedstalks per Wyoming big sagebrush. Statistical analysis was performed using a log + 1 transformation. Different letters indicate a significant difference within and across years ($P < 0.05$).