ELEMENT STEWARDSHIP ABSTRACT
for

Bromus tectorum L.
(*Anisantha tectorum* (L.) Nevski)

cheatgrass
downy brome

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SPECIES CODE
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SCIENTIFIC NAME
Bromus tectorum L. [*Anisantha tectorum* (L.) Nevski]

The genus name *Bromus* was derived from *bromos*, an ancient Greek word for a kind of oat, and the Greek word *broma*, which means food (Upadhyaya et al. 1986). The specific epithet, *tectorum*, was derived from the Latin words, *tector*, which means one who overlays, and *tectum*, which means roof (Upadhyaya et al. 1986). The genus name *Anisantha* was derived from the Greek words, *anison* (unequal) and *anthos* (flower), referring to the differential sexuality among the florets (Weber 1990). However, the synonym *Anisantha tectorum* is rarely used.

COMMON NAME

Cheatgrass and downy brome are the two most frequently used common names in North America. Additional common names include downy chess, early chess, drooping brome, downy cheat, cheatgrass brome, slender chess, downy bromegrass, military grass, broncograss, and Mormon oats (Upadhyaya et al. 1986).

DESCRIPTION AND DIAGNOSTIC CHARACTERISTICS

The following description is abstracted from Upadhyaya et al. (1986).

Bromus tectorum is an erect winter- or spring- annual grass. The seedlings are bright green with conspicuously hairy leaves, hence the alternate common name, downy brome. At maturity the foliage and seedheads often become purplish before drying completely and becoming brown or tan. The species grows quickly in the spring and often matures and sets seeds before most other species. It typically grows 50-60 cm (20-24 inches) tall, with a finely divided, fibrous root system that may reach a depth of about 30 cm (12 inches). When environmental conditions are poor and/or when grazing animals crop the plants, cheatgrass plants that reach heights of just 5-10 cm (2-4 in) can still flower and produce viable seed. The stems are erect, slender, and glabrous or may be slightly soft-hairy. The nodding, open panicles with moderately awned spikelets are very distinctive. The spikelets readily penetrate fur, socks and pants and its seeds may thus be widely dispersed by people and animals.

Panicles are 5-20 cm (2-8 in) long, and rather dense. Cheatgrass panicles change color from green to purple to brown as the plant matures and eventually dries out. Branches are slender, pubescent, flexuous, with up to eight spikelets.

Spikelets including awns are 2-4 cm (0.8-2 in) long, nodding, with 2-8 pubescent or villous florets. The glumes are villous, the lower ones 5-8 mm (0.2-0.3 in) long, and the upper ones 7-11 mm (0.3-0.4 in) long. Lemmas are toothed, 9-12 mm (0.4-0.5 in) long, lanceolate, and covered with long, soft hairs. Awns are 12-14 mm (0.5-0.6 in) long, slender and straight.

The palea is shorter than the lemma. Each floret has three stamens and the anthers are 0.5-1 mm (.02-.04 in) long.

STEWARDSHIP SUMMARY

Bromus tectorum is an alien grass that dominates disturbed ground in shrub-steppe ecosystems of the western United States and Canada (Link et al. 1995). Cheatgrass reproduces only from seeds, germinates in the fall or winter, expands its roots over winter, and rapidly exploits the available water and nutrients in early spring (Skipper et al. 1996). Cheatgrass is common in recently burned rangeland and wildlands, winter crops, waste areas, abandoned fields, eroded areas, and overgrazed grasslands (Upadhyaya et al. 1986). Although cheatgrass readily invades perennial forage crops and rangeland under poor management, it also invades communities in the absence of disturbance (Douglas et al. 1990). In undisturbed sites, cheatgrass will most commonly spread along soil cracks and work its way outward into the natural community (Rice and Mack 1991). Cheatgrass can persist in unpredictable environments because seed germination is staggered from August until May.

Cheatgrass occurs in a wide variety of habitats across the continental U.S., but it is most prominent on the Columbia-Snake River Plateau, Wyoming Basin, and the northern portion of the Great Basin in disturbed sagebrush steppe communities (Rice and Mack 1991, West 1983). Pristine sagebrush steppe ecosystems are characterized by a more or less equal dominance by woody *Artemisia* shrubs and bunchgrasses. In the past, pristine communities were dominated by generally long-lived perennials where recruitment of seedlings to the population may have occurred at irregular intervals in response to extraordinary environmental conditions (Young and Evans 1985). In contrast, the annual *Bromus tectorum* requires establishment every year (Young and Evans 1985).

Vast numbers of cheatgrass seedlings usually germinate after the first fall rain in infested areas (West 1983).   The root system continues to develop throughout most of the winter and the plant has an extensive root system by spring. This allows it to extract higher levels of soil moisture and nutrients. Cheatgrass has a compressed phenology and usually dries out and casts seeds by mid-June (West 1983). These dry plants can fuel wildfires. If fires occur frequently, perennials will likely give way to a community dominated by cheatgrass and other annuals (West 1983).

The change induced by cheatgrass in the fire cycle frequency is probably the species' greatest competitive advantage. Although fire is a natural part of the sagebrush grassland ecosystem, those fires usually occurred at intervals between 60-100 years (Whisenant 1989). Cheatgrass infested areas burn at a much greater frequency, every 3-5 years (Whisenant 1989). At this frequency, native shrubs and perennial grasses cannot recover and after a few wildfire cycles a cheatgrass monoculture develops. This monoculture further increases the frequency of fires and increases the dominance by cheatgrass in the area. Put simply, fire begets cheatgrass and cheatgrass begets fire (Devine 1998).

The vegetation of a pristine shrub-steppe ecosystem is dominated by perennial bunchgrasses and widely spaced shrubs (Whisenant 1989). Species that are commonly displaced by cheatgrass include big sagebrush (*Artemisia tridentata*), antelope bitterbrush (*Purshia tridentata*), bluebunch wheatgrass (*Agropyron spicatum = Pseudorogneria spicata*), crested wheatgrass (*Agropyron cristatum*), western wheatgrass (*Agropyron smithii = Pascopyrum smithii*), Sandberg bluegrass (*Poa sandbergii = Poa secunda*), needle-and-thread grass (*Stipa comata* = *Hesperostipa comata*), and Thurber's needlegrass (*Stipa thurberiana*).

Cheatgrass seems to grow especially well in soils with high levels of potassium (Belnap pers. comm.). Potassium levels can be measured to determine how susceptible the area may be to cheatgrass invasion. Also, it may be possible to reduce the abundance of cheatgrass by lowering the amount of potassium in the soil (Belnap pers. comm.).

Cheatgrass has a dual role as a serious weed and important early season forage for cattle and sheep (Emmerich et al. 1993, Upadhyaya et al. 1986). *Bromus tectorum* provides the bulk of early spring forage for all classes of stock on grazing lands in the Intermountain and Pacific Northwest regions (Upadhyaya et al. 1986). From a standpoint of volume and quality of herbage produced and extent of area covered, cheatgrass is undoubtedly the most important spring forage in the region (Upadhyaya et al. 1986). Additionally, cheatgrass can provide suitable forage where bare ground previously existed, and some ranchers have observed cattle selecting cheatgrass over native grasses (Emmerich et al. 1993)

While some ranchers believe that cheatgrass is highly valuable, winter wheat growers in the western U.S. and Canada proclaim it as their worst problem (Upadhyaya et al. 1986). Annually, cheatgrass costs wheat farmers an estimated $350-370 million dollars in lost yields and control costs in the western U.S. (Gurusiddaiah et al. 1994). The adoption of no-till farming practices for winter wheat and other similar crops has favored the growth and spread of *Bromus tectorum* (Douglas et al. 1990). Cheatgrass is a serious weed in winter wheat because its cold hardiness is either equal to or superior than the hardiest winter wheat cultivars (O'Connor et al. 1991). Cheatgrass densities of 108 and 538 plants/m^2 reduced wheat yields by 40 and 92% respectively (Upadhyaya et al. 1986).

Lasting control of cheatgrass will require a combination of chemical control, physical control, vegetative suppression, and proper livestock management where land is grazed. This "cumulative stress" method will keep the plants constantly under stress, reducing their ability to flourish and spread. Also, a cumulative stress approach provides a level of redundancy in case one type of treatment is not implemented or proves to be ineffective.

An effective management program needs first to control existing infestations, and second to develop a land management plan to deter re-infestation of *Bromus tectorum*. New infestations should be controlled first before cheatgrass becomes dominant and alters the soil chemistry of the area (Belnap pers. comm.). Since cheatgrass reproduces entirely by seed, the key to controlling existing infestations is to eliminate new seed production and deplete the existing seed bank.

Bromus tectorum is most commonly controlled with herbicides. Quizalofop, fluazifop, sethoxydim, paraquat, glyphosate, and imazameth can be applied in the early spring, before perennial grasses have emerged, to control cheatgrass. Additionally, sulfometuron methyl, and atrazine can be applied in the fall to control cheatgrass in winter crops. Several of these herbicides may damage established perennials. Therefore, the timing of herbicide application is crucial to ensure that cheatgrass is selectively controlled. Burning is usually conducted in late May or early June, after the plants have dried (Beck, pers. comm.). Reseeding native perennial grasses is necessary after burning or cheatgrass and other weeds will simply reestablish in the disturbed area.

A two to three-year combination of burning, herbicide application, and reseeding can be used to control and re-vegetate an area that is almost exclusively dominated by cheatgrass. Burn and re-seed the area with native perennial grasses during the first year. The following spring, apply herbicides before the seeded perennial grasses emerge in order to eliminate any cheatgrass that emerged from the seedbank after the burn. If necessary, apply a second round of herbicides early in the spring of the third year to control any new cheatgrass seedlings and provide time for native bunchgrasses to establish. This should control the cheatgrass, deplete the existing cheatgrass seed bank, and provide adequate time for perennial grasses to establish to the point where they can suppress any new cheatgrass invasions.

If the area is only partially infested with cheatgrass, burning is usually not recommended (Belnap, pers. comm.). Cheatgrass can rebound quickly after a fire and the elimination of the remaining valuable species will only enhance its ability to spread.

Hand pulling cheatgrass is very labor intensive and is worthwhile only on very small infestations. Mowing and cutting are not usually recommended methods of control. Plants that are cut before seed ripening will regenerate new culms and produce seeds at the cut height. Plants that are cut after seed ripening will die, but by this point the seeds are already viable. However, repeated mowing (every three weeks) can eliminate cheatgrass seed production in areas were herbicide applications are unacceptable or cannot be safely used.

Once an area has been treated, native perennial grasses should be plugged and/or re-seeded or cheatgrass will return to pre-burn densities within a few years (Beck, pers. comm.). Hilaria (*Hilaria jamesii*) has been observed to grow well in cheatgrass infested areas of the Colorado Plateau by taking advantage of warm summer rains (Belnap pers. comm.).

IMPACTS (THREATS POSED BY THIS SPECIES)

Seldom in recent history has the vegetation of such a large area been transformed so rapidly, and probably so permanently, as during the invasion and spread of cheatgrass in the Great Basin and Columbia Basin areas during the late 1800s and early 1900s (Upadhyaya et al. 1986). The process in which a pristine shrub-steppe ecosystem deteriorates into one dominated by cheatgrass takes several years and has several distinct cycles. First, some sort of disturbance, typically heavy grazing, allows cheatgrass and other annuals to invade and proliferate. The dry beds of cheatgrass in the summer increase the occurrence of frequent fires. Initially, this creates an environment dominated by annual grasses, matchweed (*Gutierrezia sarothrae*), and rabbitbrush (*Chrysothamnus* spp.). As fires become even more frequent, the area will be dominated by annual grasses alone, with the loss of surface soil, nutrients, and near permanent deterioration of the site (West 1979).

Today, *Bromus tectorum* is the dominant species on more than 100 million acres of the Intermountain west (Whisenant 1989). The density of cheatgrass plants in degraded grassland communities is about 10,000 to 13,000 plants/m^2 (Young and Evans 1985). At this population level 10,000 to 15,000 viable but dormant seeds/m^2 are present in the litter and surface soil (Young and Evans 1985). Even with the elimination of the current year's seed production, the seed bank is capable of renewing cheatgrass populations for two or possibly three years without noticeable reductions in plant density (Young and Evans 1985).

Although cheatgrass competes with established perennial grasses for soil moisture, its adaptation and promotion of frequent fires are what gives it the greatest competitive advantage. Cheatgrass is well adapted to fire and often dominates plant communities after fire (Melgoza et al. 1990). Once established, cheatgrass-dominated grasslands greatly increase the potential and recurrence of wildfires. In many areas that have been invaded by cheatgrass the natural fire cycle has shortened from every 60-100 years to every 3-5 years (Devine 1998, Whisenant 1989). Not only are these areas burned more often, the fires are more uniform, with fewer patches of unburned vegetation remaining within the burns (Whisenant 1989). This wildfire cycle significantly reduces the ability of perennial grasses and shrubs to re-establish, and furthers the dominance of cheatgrass.

While cheatgrass provides good quality forage when used by livestock in the early spring, it can have negative effects when consumed in late spring and summer. Mature seeds contain long, stiff awns that often puncture the mouth and throat tissue of livestock, reducing feed intake and subsequent weight gain (Currie et al. 1987). The effects on native game species are unknown.

GLOBAL RANGE

Bromus tectorum is native to Eurasia and the Mediterranean. It is now found throughout most of Europe, southern Russia, western and central Asia, Japan, South Africa, Australia, New Zealand, Iceland, Greenland, and North America (Upadhyaya et al. 1986).

Bromus tectorum is thought to have been introduced into the Intermountain west in the 1880s in impure seed (Mack 1986). The earliest records of the grass in North America are from inland wheat growing districts at Kingston, Ontario (1886); Spence's Bridge, British Columbia (1889); Ritzville, Washington (1893); and Provo, Utah (1894) (Mack 1986). A deliberate introduction was made in a college experiment in Pullman, Washington in 1898, in search of new grasses for the area (Upadhyaya et al. 1986).

At first, cheatgrass was prominent only locally, for example around railroad rights-of way. However, by the 1920s cheatgrass had become a serious problem in fields of alfalfa and wheat (Mack 1986). By 1930, the grass had reached its current distribution in the Intermountain west, and the first references to "cheatgrass lands" were being made (Mack 1986).

Presently, cheatgrass is widely distributed throughout the 48 contiguous United States (Upadhyaya et al. 1986), but is uncommon in Florida (Wunderlin 1998). Cheatgrass now occupies much of the grassland in eastern Washington, Idaho, eastern Oregon, Nevada, and Utah (Thill et al. 1984). Cheatgrass often occurs as a significant component of foothills rangeland vegetation along the eastern front of the Rocky Mountains. While cheatgrass is usually found along roadsides and disturbed sites in the east, it is highly abundant in the west and has invaded disturbed and undisturbed grassland communities to become the dominant species in many lower-elevation areas. In Canada, cheatgrass occurs in all Canadian Provinces from New Brunswick and Nova Scotia to British Columbia (Upadhyaya et al. 1986).

HABITAT

Although *Bromus tectorum* can be found in both disturbed and undisturbed shrub-steppe and intermountain grasslands (e.g., where dominant grasses are *Agropyron spicatum* = *Pesudorogneria spicata* and *Festuca idahoensis*), the largest infestations are usually found in disturbed shrub-steppe areas, overgrazed rangeland, abandoned fields, eroded areas, sand dunes, road verges, and waste places. *Bromus tectorum* is not very exacting in its requirements, but is found mostly in areas receiving 15-56 cm (6-22 in) precipitation annually (Upadhyaya et al. 1986). Continuous late summer or early fall rains are necessary for rapid germination and fall growth of cheatgrass (Upadhyaya et al. 1986). Cheatgrass will grow on almost any soil but has been reported to prefer coarse-textured soils and does not flourish on extremely heavy or dry soils (Upadhyaya et al. 1986). Cheatgrass has been found at elevations up to 4,000 m (13,123 ft) and above in the United States (Hunter 1991), and has been recorded at elevations up to 3,000 m (9,843 ft) in the Himalayas (Upadhyaya et al. 1986).

Cheatgrass does not flourish in the mature forest zones of the Intermountain region of western North America. The inability of *Bromus tectorum* to establish persistent populations under most forest canopies is attributed to the influence of shade on the plant's photosynthetic rate and resource allocation, the short growing season at high altitudes where forests are present in the west, and the role of herbivory in exacerbating the first two factors (Pierson and Mack 1990). Consequently, these forest zones broadly define the current environmental limits of the distribution of cheatgrass in western North America (Pierson and Mack 1990).

BIOLOGY-ECOLOGY

Bromus tectorum has a flexible lifecycle though it is generally regarded as a winter annual (Young and Evans 1985). The ability of cheatgrass to invade and persist over a wide range of physically and biologically diverse environments may result from a combination of genetic polymorphism and phenotypic plasticity (Rice and Mack 1991).

The success of *Bromus tectorum* depends to a large extent on its ability to utilize moisture from the upper layers of the soil (Upadhyaya et al. 1986). Cheatgrass has a finely divided root system, which penetrates to depths of around 30 cm (11.8 in), allowing it to extract most or all of the available moisture from this shallow layer of the soil profile (Upadhyaya et al. 1986). The roots of *Bromus tectorum* continue to grow during the winter, allowing it to gain control of a site before the seedlings of other species are established (Young and Evans 1985).

Cheatgrass has greater top-growth yields per unit water used compared to summer growing perennial grasses (Upadhyaya et al. 1986). This high water-use-efficiency is in part due to its early season growth when transpiration rates are low. In hot weather, *Bromus tectorum* roots are unable to supply enough moisture to prevent a drop of leaf water potential, resulting in the desiccation and death of the plant (Upadhyaya et al. 1986).

Cheatgrass displays a "big bang" type of reproductive behavior with no post-reproductive lifecycle (Upadhyaya et al. 1986). Cheatgrass is a highly self-pollinating species and hybridization with other species rarely occurs under natural conditions (Upadhyaya et al. 1986). Cheatgrass generally produces so many seeds that plant density is not related directly to the number of seeds present, but to the number of available sites in the seedbed capable of supporting germination (Young and Evans 1985). Generally, the seedlings that germinate in the fall and survive until maturity are the healthiest, and become the most prolific seed producers.

Bromus tectorum normally germinates in the fall. Heavy, late summer and early fall rains as well as the microtopography of the soil surface affect the germination and seedling emergence (Upadhyaya et al. 1986). Cheatgrass seeds will not normally germinate on a bare surface and require a cover of litter or mulch to germinate (Young and Evans 1978). If moisture in the fall is inadequate, cheatgrass seeds may germinate in the spring, and act as a spring annual (Upadhyaya et al. 1986).

The leaves typically grow little in the fall, and plants are normally 2-4 cm (0.8-2 in) high when covered by snow around December. The young, fall-germinated seedlings often over-winter in a semi-dormant state and complete their lifecycle the following spring (Upadhyaya et al. 1986). *Bromus tectorum* shoots grow rapidly in early spring and soil temperature appears to be the most important factor (Upadhyaya et al. 1986). Cheatgrass roots can grow in soil temperatures approaching freezing (West 1983), and cheatgrass roots will continue to grow throughout the winter until soil temperatures drop below about 28ºC (37ºF).

In the spring, fall-germinated plants have the advantage of an established root system and photosynthetic area, while spring-germinated plants are struggling through seedling establishment (Young and Evans 1985). Roots continue to grow until spring and then their growth rates decline rapidly. Plants head in late April to early May followed by anthesis within a week (Upadhyaya et al. 1986).

The seeds reach the soft dough-stage in mid to late May, and mature in mid to late June (Upadhyaya et al. 1986). The anthers of *Bromus tectorum* florets open over about an eleven day period. Cheatgrass seeds shatter within a week after maturity (Upadhyaya et al. 1986). Seeds are dispersed short distances by wind, and the long awns can attach to the fur or feathers of animals, as well as clothing. If precipitation is adequate, the majority of cheatgrass seeds will germinate in the fall, or within a year of maturation (Upadhyaya et al. 1986). However, dry conditions can cause environmentally induced dormancy, which may last several years and break down at erratic intervals (Young and Evans 1985).

Cheatgrass can be a prolific seed producer with production of 450 kg seeds/hectare reported (Upadhyaya et al. 1986). Seed production per culm, per plant, and per unit area is dependent on plant density and environmental factors (Upadhyaya et al. 1986). Average seed production per plant is generally lowest when the plant density is highest (Rice and Mack 1991). However, plants as small as 2.5-5.0 cm (1-2 in) tall, growing under low moisture conditions can produce some seeds (Upadhyaya et al. 1986).

During ripening, cheatgrass inflorescences turn purple and then brown as they mature. Once the seeds have matured, cheatgrass plants dry and become flammable. There is a correlation between plant color and moisture status during the drying process (5). Cheatgrass passes from green (>100% moisture content), to a purple hue (30-100% moisture content), to a straw color (<30% moisture content) as it dries (5). The onset of purple coloring should be taken as a warning that hazardous fire conditions will develop within two weeks (5).

RESTORATION POTENTIAL

The restoration potential of areas cleared of cheatgrass has not yet been determined (but see the Management Programs Section). The large seed bank of *Bromus tectorum* may allow it to re-invade even after several years of control (Wicks 1997). Areas that have been cleared of cheatgrass should be reseeded with native perennial plants to enhance the recovery of the site. Even though cheatgrass uses soil water efficiently at shallow depths compared to perennial grasses, once the root of a perennial grass penetrates below 0.5 m (19.7 in), it is relatively free from competition with cheatgrass roots. Once perennial grasses have established themselves, and their roots have grown to depths below the cheatgrass root zone, they can more effectively compete with *Bromus tectorum*.

Crested wheatgrass, a plant native to Asia and tolerant of heavy livestock grazing, can be planted to compete with cheatgrass on disturbed rangeland. However, cheatgrass plants are still considered superior competitors (Francis and Pyke 1996), and in some cases cheatgrass may suppress crested wheatgrass (Aguirre and Johnson 1991).

Idaho fescue (*Festuca idahoensis*) is a native perennial bunchgrass that persists within high densities of cheatgrass (Nasri and Doescher 1995). Idaho fescue plants from degraded areas proved to be more effective competitors than plants from pristine areas (Nasri and Doescher 1995). This suggests that continual competition with cheatgrass selected for a hardier, more competitive, group of Idaho fescue plants. Hence, seeds from Idaho fescue plants in cheatgrass infested areas may prove to be more successful at suppressing cheatgrass when planted elsewhere.

MONITORING REQUIREMENTS AND PROCEDURES

In many situations determining the relative cover of cheatgrass is difficult due to the fluctuations in cover between years in accordance with weather variations. Estimates of cheatgrass coverage should be designed to determine how dominant cheatgrass is in the area compared to other vegetation. Areas should be monitored every spring, and the relative coverage and boundaries of any infestation should be recorded. Special attention should be paid to roadsides and other disturbed areas where cheatgrass is commonly found, or areas where roads are the most likely route of introduction. If an infestation is found, the location should be recorded and monitored to measure the rate in which the infestation is spreading.

MANAGEMENT PROGRAMS

An extensive experimental management program has been conducted on the Lawrence Memorial Grassland Preserve in Oregon. In this “biscuit scabland,” or mounded prairie grassland, cheatgrass and medusahead (*Taeniatherum caput-medusae*) invaded areas that were disturbed by gophers and the introduced grasses subsequently excluded native bunchgrasses (Ponzetti 1997). A multi-stage approach using prescribed burns, herbicide application, and mowing was developed to prevent annual grass seed maturation (Ponzetti 1997). The infested areas were burned during the first week of July to destroy the current year’s seed production (Ponzetti 1997). Over the next two springs, the infested areas were either mowed with a weed-eater or treated with glyphosate (at 2 ounces/gallon H_20) in order to eliminate any plants that emerged from the existing seed bank (Ponzetti 1997). Additionally, six-month old plugs of bluebunch wheatgrass, Idaho fescue, and squirreltail (*Sitanion hystrix*) were planted to help repopulate the areas with native species (Ponzetti 1997).

The results from the first two years of this study indicated that one year of treatment with glyphosate or mowing was equally effective at controlling cheatgrass after a prescribed burn (Ponzetti 1997). The glyphosate seemed to negatively affect the survivorship of *Sitanion hystrix* and *Poa secunda* and any herbicide may need to be applied earlier in the spring to minimize the damage to non-target plants. Mowing was significantly more labor intensive and had to be repeated every three weeks during a wet spring as the mowed cheatgrass plants tillered and produced new seeds at the cut height.

This experiment concluded that either treatment is more effective than no treatment (Ponzetti 1997). This is an on-going study and a third year of treatment will help determine if the exotic grasses can be reduced further, and determine if one technique is more effective than the other.

BIOLOGICAL CONTROL

No biological control agents are available for use against cheatgrass at present. The biological control of weeds is based on the premise that insect feeding stresses or kills plants or reduces seed output and eventually causes a reduction in weed density (Berube and Myers 1982). Biological agents have never been known to completely eliminate the host species, but can significantly reduce their abundance. In fact, complete elimination would be self-defeating to the control agent. However, if different stresses on plants are cumulative, biological controls which lower the competitive ability of weeds should enhance the effectiveness of other control methods.

In laboratory and small-scale field tests, phytotoxins produced by the naturally occurring rhizobacteria, *Pseudomonas fluorescens* (strain D7), and *Pseudomonas syringae* (strain 3366) adversely affected cheatgrass at several growth stages (Gealy et al. 1996, Gealy et al. 1995). These bacteria produce plant suppressive compounds (PSC's) that selectively inhibit the germination and early root growth of cheatgrass, and thus shift the competitive advantage back to perennial grasses (Ogg et al. 1991). The active compound produced by these bacteria appears to be a phenazine-1-carboxylic acid (Gealy et al. 1996). When purified from strain 3366 and applied at a rate of 5.7 mg/L, the acid inhibited downy brome root growth by 99% (Gealy et al. 1996).

The phytotoxins produced by strain D7 and strain 3366 inhibit lipid synthesis and disrupt membrane integrity (Gealy et al. 1996). These two effects can stop cheatgrass seedling growth within several hours after exposure (Gealy et al. 1996). Further tests indicated that cheatgrass root growth is about 200 times more sensitive to D7 than shoot growth (Gealy et al. 1996). Gealy et al. (1996) determined that older seedlings were inhibited several orders of magnitude less than very young seedlings. The greatest suppression of cheatgrass occurred in cool (10/10 or 18/13ºC) (50/50 or 64.4/55.4ºF) or moist conditions (Johnson et al. 1993). Since cheatgrass seeds usually germinate and establish in the fall, the application of bacterium would need to be timed to coordinate with seedling emergence.

Neither of these two rhizobacteria are currently approved as biological controls for cheatgrass. The focus of the research on them has been to develop a biological control for cheatgrass in winter wheat crops and the effects of these rhizobacteria on desirable plants in noncrop applications has not been determined. Additional research may be able to determine if these agents can provide effective control of cheatgrass on the ground in noncrop situations and natural areas.

CONTROL WITH BURNING

Bromus tectorum is a highly flammable species due to its complete summer drying, its fine structure, and its tendency to accumulate litter (5). A fire will reduce the plants to ash, but fire intensity may not be great enough to consume the litter layer, and seeds in the soil will probably survive (5). The amount of litter or ash left on a site is a good indicator of the amount of cheatgrass seed still surviving (5).

Wendtland (1993) studied the effects of spring, summer, and fall burns on mixed-grass prairie in western Nebraska that had been tilled in the distant past and had subsequently reverted to prairie ("go-back" lands). The study sites had abundant cheatgrass. He found that both summer and fall burns were effective at controlling cheatgrass without severely damaging most native species plants. However, he recommended fall burns because they were much easier to control than summer burns. Interestingly, blue grama (*Bouteloua gracilis*), which is often the dominant plant over vast areas of short-grass prairie, was damaged significantly more by burning than other native plant species.

In Colorado, burning is usually conducted in June after the plant has dried, but before the seeds have dropped (Beck pers. comm.). However, some seeds will survive and if a burn is not followed by reseeding cheatgrass will recover to pretreatment proportions within 3 to 4 years (Beck pers. comm.). Reseeding should be done in late fall (a dormant seeding) (Beck pers. comm.).

Cheatgrass fires may reduce the cover of valuable perennial species e.g., shrubs like sagebrush and grasses like bluebunch wheatgrass, that are not adapted to frequent fires (5). Additionally, areas that have been burned become susceptible to erosion until they green up again.

Cheatgrass fires can burn very rapidly and can be very dangerous. Firefighters have reported cheatgrass fires that traveled between 20-40 mph, over-running firefighters and equipment (Devine 1998). Controlled cheatgrass burns should always be conducted by trained individuals.

CONTROL WITH CHEMICALS

There are several types of herbicides that can be used alone or combined to provide effective control of *Bromus tectorum*. For relatively small infestations, a backpack sprayer is recommended to minimize the danger to non-target plants. However, infestations are often so large that a four-wheeler, tractor, or truck fitted with a sprayer is necessary. The following herbicides are divided into two groups, spring applied and fall applied.

Spring Applied Herbicides

In most cases, applications should be made in early spring when non-target species are dormant to ensure selective control. Cheatgrass was reported to be controlled best when the plants were 10 cm (3.9 in) high or less and growing vigorously at the time of application (Wiese et al. 1995).

Quizalofop

Trade Name: Assure II®

Whitson et al. (1988) reported that quizalofop applied in mid-April at a rate of 0.5 lb./acre controlled 100% of the cheatgrass in the study. However, the herbicide suppressed seed head production of perennial grasses (Whitson et al. 1988). In another study, quizalofop at 0.02 lb./acre provided greater than 95% control of cheatgrass. No mention was made of damage to perennial grasses (Wiese et al. 1995).

Quizalofop is a grass meristem destroyer, and is usually used to remove grass species from any non-grass crop (Ross and Childs 1996). All grass meristem destroyers should be used post-emergence on seedling grasses before the seed head is detectable in the top leaf sheath (boot stage) (Ross and Childs 1996). Once applied, leaves yellow, redden, and sometimes wilt (Ross and Childs 1996). Quazalofop does not damage most broadleaf species and is registered in the United States for noncrop use outside California (DuPont, 1999a).

Fluazifop-p-butyl

Trade names: Fusilade® 2000, Fusilade® DX

Fluazifop-p-butyl is another postemergence herbicide that attacks the meristematic tissue of annual and perennial grass species (Ross and Childs 1996). Fluazifop-p-butyl is actively taken up and translocated throughout the plant (7). It accumulates in the actively growing regions and interferes with the plant cell's ability to produce energy (7). Fluazifop-p-butyl does not kill broadleaved plants, and at sublethal rates will suppress seed head development in cheatgrass (Ahrens 1994). At very low rates, fluazifop-p-butyl retards grass growth (Ahrens 1994). However, if considering using low rates of fluazifop-p-butyl against cheatgrass, the herbicide's effects on desireable non-target grass species should be determined on a site by site basis.

The application rate in noncrop situations is generally 16-24 oz/acre (1-1.5 lb./acre). Like quizalofop, fluazifop-p-butyl should be applied early post-emergence, before the seed head is detectable in the top leaf sheath (Ross and Childs 1996). Fluazifop-p-butyl is not registered for use on *Bromus tectorum* in California.

Sethoxydim

Trade names: Poast®, Poast Plus®

Sethoxydim is a postemergence herbicide used to control annual and perennial grass species (8). Like quizalofop and fluazifop it does not damage most broadleaved species (forbs and woody plants). Sethoxydim is commonly used to control grass weeds in broad-leaved vegetable, fruit, field and ornamental crops (8). Sethoxydim has been used in noncrop situations as well. It is registered for "set aside conservation reserve land" in the Midwest, South and Northeast. Except in California, it is registered throughout the U.S. for noncrop use (BASF, 1999).

Sethoxydim shows some selectivity among grass species, particularly among cool season grasses (Ross and Childs 1996). Sethoxydim should be applied early postemergence before the grass reaches the boot stage.

Paraquat

Trade Name: Gramaxone®

Paraquat applied at 0.5 to 0.7 lb./acre controlled greater than 97% of cheatgrass when applied during late April or early May (Whitson et al. 1993). Blackshaw (1991) reported that paraquat at 0.22 to 0.27 lb./acre controlled cheatgrass by 80-90% when applied up to the 3-5 tiller stage.

Paraquat is a contact herbicide that kills only the tissue contacted. Paraquat penetrates into the cytoplasm and causes the formation of peroxides and free electrons which destroy the cell membranes almost immediately (Ross and Childs 1996). Severe injury is evident hours after application and maximum kill is attained within a week (Ross and Childs 1996). If the plant is only partially covered with herbicide, only partial shoot kill will occur. Any new growth on the surviving plants will be normal in appearance, and foliar applications alone can only provide shoot kill (Ross and Childs 1996).

Glyphosate

Trade Names: Roundup®, Roundup Ultra®, Rodeo®, Accord®

Glyphosate applied when cheatgrass plants have 3-5 tillers at a rate of 0.16 to 0.18 lb./acre controlled cheatgrass by 80-90% (Blackshaw 1991). However a different experiment by Beck et al. (1995) using glyphosate at a much higher rate of 0.37 to 0.5 lb./acre resulted in only 80% reductions of cheatgrass within and between years. Glyphosate is a non-selective herbicide and will damage or kill desirable vegetation that it contacts including forbs and woody species. It should be applied in early spring after cheatgrass has established, but before perennial seedlings have emerged.

Glyphosate is an amino acid inhibitor (Ross and Childs 1996). It is a relatively non-selective compound that is used to control annual grasses and broad-leaved plants. Uses are limited to foliar applications only, as it is quickly inactivated in the soil (Ross and Childs 1996). Symptoms include yellowing of new growth and death within days to weeks (Ross and Childs 1996).

Imazameth

Trade Name: Plateau®

Imazameth can be applied at a rate of 0.24 to 0.75 lb./acre to newly established or existing stands of big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), sideoats grama (*Bouteloua curtipendula*), and blue grama (*Bouteloua gracilis*) to control cheatgrass, as well as other annual and perennial weeds (1,6). Plateau® is new herbicide that provides a broad spectrum of weed control for roadsides and native grasses in noncrop applications (3). It controls annual and perennial weeds without adverse effects on cool or warm season perennial grasses (1,2). Brian Winter, a TNC steward in Minnesota, used Plateau® to control leafy spurge (*Euphorbia esula*). He notes that it effectively controls cool season grasses and forbs, but leaves the warm season native grasses. It is labeled for use during the re-establishment of native grass prairie, but is not labeled for use in pastures, rangeland, or along streamsides (2).

Imazameth is an amino acid inhibitor that has a long residual life in the soil, and may leach into groundwater. It should not be used around streams and rivers (2). When applied, shoot meristems cease growth and roots tend to develop poorly (Ross and Childs 1996). Complete symptom development can be very slow and may take two to three weeks to develop (Ross and Childs 1996).

Fall Applied Herbicides

Fall herbicide applications should be conducted after cheatgrass seeds have germinated and are beginning to grow. Fall applications are generally used in cropland situations by farmers growing winter wheat or other cool season crops. However, sometimes these herbicides are used in pastures and rangelands.

Sulfometuron Methyl

Trade Name: Oust®

Sulfometuron methyl is a pre-emergence and post-emergence herbicide that controls many annual and perennial grasses and broadleaf weeds in noncrop areas (Dupont 1999b). Apply sulfometuron methyl at a rate of 3 to 5 oz/acre (0.2-0.3 lb./acre) for cheatgrass control (9). Masters (1998) found sulfometuron methyl has only a minimal effect on native perennial grasses and is helpful, when fall applied with imazapyr, in re-establishing native grasses.

Sulfometuron methyl is an extremely potent herbicide and can damage non-target vegetation if it is not applied correctly. Users should read the product label carefully before applying sulfometuron methyl to any area.

Atrazine

Trade Name: Aatrex®

In one experiment, atrazine at a rate of 0.54 lb./acre was the most cost-effective herbicide for decreasing competition of annual brome grasses and increasing yields of perennial grasses (Currie et al. 1987). In addition to suppressing cheatgrass, atrazine seems to stimulate protein production on native shortgrass range (Currie et al. 1987).

Atrazine is a pre-emergence, and to a limited extent early post-emergence, photosynthetic inhibitor that is mainly used in crops, but is sometimes used in pastures, rangeland, and noncropland (Ross and Childs 1996). It is registered for use on roadsides in Colorado, Kansas, Montana, North Dakota, Nebraska, South Dakota and Wyoming. In conservation reserve programs, Atrazine may be used in Nebraska, Oklahoma, Oregon and Texas (Novartis, 1999). Atrazine kills cheatgrass seedlings in the fall after they emerge from the soil while perennial plants are dormant. The following spring, the area is free of cheatgrass, and clear for the establishment of native perennial grasses. The half-life of atrazine in the soil ranges from 60-100 days. Atrazine is highly mobile in soil and has a high potential for groundwater contamination.

More information on chemical control of cheatgrass can be obtained from the Weed Management Library at 1-800-554-WEED, or from your State Weed Specialist.

Arizona: Everett Hall: Arizona Department of Agriculture, Plant Services, 1688 West Adams, Phoenix, AZ 85007; telephone: (602) 542-3309; e-mail: adaphyx18@getnet.com

California: Joseph DiTomaso: University of California Davis, 210 Robbins Hall, University of California, Davis, CA 95616-8746; telephone: (916) 754-8715; e-mail: ditomaso@vegmail.ucdavis.edu

Colorado: George Beck (weed control specialist): Colorado State University, C 120 Plant Sciences Building, Fort Collins, CO 80523-6021; telephone: (970) 491-7568; e-mail: gbeck@lamar.colostate.edu

Idaho: Robert Callihan (retired): University of Idaho, AS 317 General Services, Moscow, ID 83844-2339; telephone: (208) 885-6617; e-mail: bccallihan@uidaho.edu

Montana: Harold Stepper (weed control specialist): Montana Department of Agriculture, P.O. Box 200201, Helena, MT 59620; telephone: (406) 444-5400

New Mexico: Richard Lee (weed control specialist): New Mexico State University, Extension Plant Services, Box 30003, Department 3AE, Las Cruces, NM 88003; telephone: (505) 646-2888; general e-mail: crops@nmsu.edu

Oregon: Tim Butler: Oregon Department of Agriculture, Noxious Weed Control Program, 635 Capitol St. NE, Salem, OR 97310-0110; telephone: (503) 986-4625; e-mail: tbutler@oda.state.or.us

Utah: Steve Dewey (extension weed specialist): Utah State University; Plants, Soils, and Biometeorology Department, Logan, UT 84322-4820; telephone: (801) 750-2256; e-mail: steved@ext.usu.edu

Washington: Greg Haubrich (state weed specialist): Washington Department of Agriculture, 2015 South 1st St., Yakima, WA 98903; telephone: (509) 576-3039; e-mail: ghaubrich@agr.wa.gov

Wyoming: Tom Whitson (weed science specialist): University of Wyoming, Department of Plant Science, P.O. Box 3354, Laramie, WY 82071-3354; telephone: (307) 766-3113; e-mail: twhitson@uwyo.edu

CONTROL WITH CUTTING

Cutting is not a recommended control method for cheatgrass. Plants that are cut before seed ripening will regenerate new culms and produce seeds at the cut height. Plants that are cut after seed ripening will die, but by this point the seeds are already viable. For more information, see Lawrence Memorial Grassland Experiment in the Management Programs Section.

CONTROL WITH GRAZING, DREDGING, AND DRAINING

Bromus tectorum is considered to be valuable forage in some ranching operations (Emmerich et al. 1993). However, grazing is not a recommended method of control for cheatgrass. If the plants are grazed in the spring, they will regenerate new culms and produce seeds. When grazed in the summer or fall the plants will not regrow, but by then viable seeds have already been produced. Also, the long awns of the seeds on the mature plants may damage the mouths and intestinal tracts of the livestock.

There are no references to indicate that dredging or draining have been tested, or would be an adequate control method for *Bromus tectorum*. Cheatgrass does not usually grow in sites that could be dredged or drained.

CONTROL WITH MANIPULATION OF WATER LEVEL AND SALINITY

There are no references to indicate this has been tested, or would be an adequate control method for *Bromus tectorum*.

CONTROL WITH MOWING, DISKING, AND PULLING

Mowing is not usually an effective control of *Bromus tectorum* (Whitson et al. 1997). Although cheatgrass plants will die if they are mowed after ripening, by then the seeds are already viable. When mowed at an earlier growth stage, the plants can regenerate new culms and produce viable seeds. Therefore, mowing once a year does not prevent stands from producing viable seeds (Whitson et al. 1997).

In one study, repeated mowing (every three weeks) during the spring and summer was as effective at controlling cheatgrass seed production as an application of glyphosate (Ponzetti 1997). However, this method was very labor-intensive and a cost/benefit analysis should be conducted before any choice is made.

Hand-pulling cheatgrass plants in small infestations before seed set would effectively eliminate current seed production, but may not eliminate the infestation. The large seed bank commonly associated with cheatgrass infestations will allow plants to re-establish for several years without noticeable reductions in plant density. Hence, any pulling program must be conducted for several years, or until the seed bank has been exhausted. Also, seeds that blow into the cleared areas from adjacent uncleared areas may negate the effects of pulling. When pulling, an effort should be made to extract as much of the root as possible so that the plant can not simply regrow and produce new seeds.

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