Restoring native species to crested wheatgrass dominated rangelands

by Janel Denice Johnson

A thesis submitted in partial fulfillment of the requirements for the degree Of Master of Science In Range Science
Montana State University

Abstract:
In the 1980's, there were an estimated 7 to 12 million ha of crested wheatgrass (Agropyron cristatum (L.) Gaertn.) in North America. Dense stands of crested wheatgrass lack species diversity, which negatively affects populations of wild mammals, birds, and reptiles. There is new interest among land managers in replacing stands of crested wheatgrass with native species for wildlife habitat, using minimal disturbance techniques such as herbicide and no-till seeding.

The objectives of this project were to (1) evaluate the effects of glyphosate on crested wheatgrass and other species and (2) test seedling establishment of native grass and forb seed mixes planted in glyphosate treated crested wheatgrass sod with a no-till drill.

Field trials were conducted with two herbicide application treatments and five planting treatments in 2002 and 2003 at five sites in central and eastern Montana. Crested wheatgrass biomass and seedling biomass index were collected in 2002 and crested wheatgrass, seeded species, and non-target species biomass were collected in 2003.

Results from the field trials indicate that applying glyphosate in the spring was effective at reducing the biomass of crested wheatgrass for two seasons and shifting the dominance in the stands toward native or weedy species, depending on the plant and seedbank composition. Application of glyphosate increased diversity at sites with low initial diversity but not at sites with high initial diversity.

Seeding was generally not successful, due primarily to lack of moisture and nitrogen. Switchgrass (Panicum mrgatum L.) and slender wheatgrass (Elymus trachycaulus (Link) Gould ex Shinners) were the most successful seeded species. Other native bunch grasses and forbs did not establish well. Because of the high cost of native seed and no-till drilling, this treatment is not recommended unless there is sufficient moisture and nutrients in the soil at the time of planting to support seedling growth.

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APPROVAL

Of a thesis submitted by

Janel Denice Johnson

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

In the 1980's, there were an estimated 7 to 12 million ha of crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) in North America. Dense stands of crested wheatgrass lack species diversity, which negatively affects populations of wild mammals, birds, and reptiles. There is new interest among land managers in replacing stands of crested wheatgrass with native species for wildlife habitat, using minimal disturbance techniques such as herbicide and no-till seeding.

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Results from the field trials indicate that applying glyphosate in the spring was effective at reducing the biomass of crested wheatgrass for two seasons and shifting the dominance in the stands toward native or weedy species, depending on the plant and seedbank composition. Application of glyphosate increased diversity at sites with low initial diversity but not at sites with high initial diversity.

Seeding was generally not successful, due primarily to lack of moisture and nitrogen. Switchgrass (*Panicum virgatum* L.) and slender wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shinners) were the most successful seeded species. Other native bunch grasses and forbs did not establish well. Because of the high cost of native seed and no-till drilling, this treatment is not recommended unless there is sufficient moisture and nutrients in the soil at the time of planting to support seedling growth.

INTRODUCTION

Crested wheatgrass (*Agropyron desertorum* (Fisch.) Schult. & *A. cristatum* (L.) Gaertn.) was introduced to North America from Asia in the 1890's. During the drought and depression of the 1930's, millions of hectares of former cropland were seeded to crested wheatgrass to stabilize loose soil (Rogler and Lorenz 1983). Crested wheatgrass has remained popular because it produces more forage than native grasses and is tolerant of drought and grazing pressure (Caldwell et al. 1981). In the 1980's, there were an estimated 7 to 12 million ha of crested wheatgrass in North America (Rogler and Lorenz 1983, Holechek 1981).

Despite its usefulness, large plantings of crested wheatgrass have some negative ecological impacts. Dense stands exclude native grasses, forbs, and shrubs that add species diversity to grassland habitats. A lack of diversity negatively affects populations of native mammals, birds, and reptiles (Reynolds and Trost 1980). Wildlife managers recognize the need to reintroduce native plants and increase diversity to provide habitat for native mammals and birds.

REVIEW OF LITERATURE

There is new interest in replacing stands of crested wheatgrass with native species using minimal disturbance techniques. The purpose of this chapter is to review the literature concerning the suppression of crested wheatgrass and establishment native grasses and forbs.

Crested Wheatgrass Suppression

Resident vegetation competes strongly with seedlings for nutrients and water, so it must be reduced or eliminated when planting native grasses. Most seedings fail when surrounding vegetation is not suppressed (Bakker et al. 1997, Wilson and Gerry 1995, Peat and Bowes 1995). Many recent experiments to replace crested wheatgrass and other pasture grasses with native species were conducted in southern Saskatchewan and Manitoba, where soils and climate are similar to central and eastern Montana.

Grazing

Grazing by cattle or sheep is not effective for removing crested wheatgrass from a seeded area. Although heavy grazing reduces production (Austin et al. 1983), stands recover quickly when removed from grazing pressure, doubling yields two years after grazing ceased (Hull and Klomp 1966). Twenty to forty year old pastures grazed annually had high densities of crested wheatgrass with minor invasions of native species (Looman and Heinrichs 1973).

Fire

In the Sandhills of southern Saskatchewan, burning in the fall to rejuvenate pastures reduced the yield of crested wheatgrass in the first season following treatment but production in following years equaled or exceeded the control by up to 170 kg ha^{-1} (Lodge 1960). Spring burning reduced the yield of crested wheatgrass pastures for two years by 450 to 1100 kg ha^{-1} but did not alter the species composition of the stand. Romo et al. (1994) combined fall or spring burning with herbicide treatment while testing methods to suppress crested wheatgrass. The results were not different from unburned herbicide treatments ($P>0.05$).

Mechanical

Two types of mechanical treatments commonly used on crested wheatgrass stands are scarification and rototilling or double disking. The effect on crested wheatgrass depends on the amount of disturbance caused by the treatment. Scarification, or ripping, only partially disturbs the stand and increases production by 15 to 45% for five years after treatment (Peat and Bowes 1995, Lorenz and Rogler 1962). Rototilling or disking reduces the cover of crested wheatgrass by 72 to 87% (Bakker et al. 1997, Wilson and Gerry 1995) and provides a better seedbed for grass seedings than no tillage. No-till dryland seedings of sand bluestem (*Andropogon gerardii* var. *paucipilus* (Nash) Fern.), switchgrass (*Panicum virgatum* L.), intermediate wheatgrass (*Thinopyrum intermedium* (Host) Barkw. & D. R. Dewey), and smooth brome (*Bromus inermis* Leyss.) into crop residues produced only 1 to 5 seedlings m^{-2} at the end of the growing season. Seed of the same species drilled into tilled ground at the same time produced 14 to 25 seedlings m^{-2} (King et al. 1989).

The drawbacks of tillage and scarification are: the surface susceptible to wind and water erosion until the seeded grasses develop, disruption of the soil structure affects soil moisture and nutrient cycling, and disturbance of the soil brings seeds of undesirable species to the surface (Baker et al. 1996). Tillage also damages desirable, native plants that may be present in the stand.

Partial mechanical disturbance of stands, such as ripping, only stimulates the growth of crested wheatgrass and is not an appropriate tool for suppression. Tilling is a good tool for areas with low erosion potential, and few desirable species, but is not suitable for areas where erosion and preservation of native plants in the stand are concerns.

Herbicide

Herbicides are a low disturbance method to control crested wheatgrass for one or more growing seasons. In Manitoba, Gobin (1994) used mowing, Gramoxone® (paraquat), Lontril® (clopyralid), Poast® (sethoxydim), and Roundup® (glyphosate) to control timothy (*Phleum pratense* L.) and smooth brome prior to seeding with tall wheatgrass (*Thinopyrum ponticum* (Podp.) Barkw. & D. R. Dewey), switchgrass, green needlegrass (*Nassella viridula* (Trin.) Barkworth), and thickspike wheatgrass (*Elymus lanceolatus* (Scribner & J.G. Smith) Gould). Plots treated with glyphosate, a non-selective herbicide, had 1300 to 1700 kg ha^{-1} less dry matter accumulation than control plots and 300 to 700 kg ha^{-1} less than other herbicide treated plots at 86 or 95 days after treatment. Seedlings in glyphosate treated plots did not have the greatest seedling densities at 100 days after seeding but did have the greatest seedling development (Haun Stage), exceeding other herbicide treated plots by 0.5 to 5.9 Haun stages by 100 days after seeding. Haun stage at the end of the growing season was correlated with in-season (R=0.733) and over-winter (R=0.909) survival rate of seedlings. Glyphosate treated plots had the greatest in-season survival rates, 88 and 97%, and over-winter survival rates, 43 and 85%, of any suppression treatment. Gobin (1994) concluded that glyphosate application resulted in the least competition from resident vegetation and was the best choice of the four herbicides for controlling resident vegetation when seeding desired species.

Other researchers applied glyphosate to control crested wheatgrass. In Saskatchewan, applying glyphosate in the spring reduced crested wheatgrass cover in most treatment plots by 20 to 70% (Bakker et al. 1997). Combining glyphosate application with rototilling did not decrease crested wheatgrass cover in the valley plots (cover = 14% spray only, 12% spray + rototill), but decreased crested wheatgrass cover in upland plots (cover = 31% spray only, 15% spray + rototill). Very low rainfall at the upland site may have caused differences between sites. In pasture improvement trials, applying glyphosate in the spring at 1.1 kg ha^{-1} with minimal disturbance of crested wheatgrass fields yielded 400 kg ha^{-1} less crested wheatgrass than control plots (Peat and Bowes 1995). This treatment also had the greatest yield of seeded alfalfa (*Medicago sativa* L.) (760 kg ha^{-1}) compared to partially disturbed (520 kg ha^{-1}) and fertilized (290 kg ha^{-1}) treatments. These studies show that applying glyphosate alone controls crested wheatgrass adequately while allowing seeded species to establish.

Timing of application is an important factor when using glyphosate. Peat and Bowes (1995) conducted trials to test the effectiveness of glyphosate applied at different growth stages. Their data show that applying glyphosate after crested wheatgrass is greater than 15 cm tall is much less effective than applying at 8 to 15 cm height (Table 1). Seeded alfalfa yields were 17 times higher in early vs. late-treated plots. They concluded that glyphosate application followed by sod-seeding in early spring was a good method for establishing desired species in old crested wheatgrass stands.

Table 1. Comparison of crested wheatgrass (CWG) suppression techniques.

Treatment (Citation)	Percent yield of crested wheatgrass compared to control
Spring Burn (Lodge, 1960)	45
Fall Burn (Lodge, 1960)	52
Scarification 10 cm shovels (Peat and Bowes, 1995)	144
Scarification 8 cm shovels (Lorenz and Rogler, 1962)	115
Rototilling (Bakker et al., 1997)	28
Gramoxone (Paraquat) (Gobin, 1994)	41
Poast (Sethoxydim) (Gobin, 1994)	65
Glyphosate (Gobin, 1994)	23
Glyphosate (Spring) (Bakker et al., 1997)	74 to 30
Glyphosate (Spring) (Wilson and Gerry, 1995)	20
Glyphosate (CWG headed) (Peat and Bowes, 1995)	77
Glyphosate (CWG 8 to 15 cm) (Peat and Bowes, 1995)	1

Crested wheatgrass begins to grow earlier in the spring than most native species (Caldwell et al. 1981), so mixed stands can be treated with a short-acting, non-selective herbicide, such as glyphosate, when crested wheatgrass is growing and native species are still dormant. Romo et al. (1994) treated an old crested wheatgrass stand at the three to five-leaf stage or at advanced boot stage by wick application of glyphosate at a height that would only contact the crested wheatgrass. This reduced the relative basal cover of crested wheatgrass from 78%, in control, to 35 or 55%, respectively, of total basal cover and increased the relative cover of native species correspondingly. In mixed stands of crested wheatgrass and native species it may not be necessary to plant native species if glyphosate is applied only to crested wheatgrass and native species are dormant or not treated.

Herbicides provide a window of reduced competition for planted species; crested wheatgrass is reduced, but not eliminated, by a single herbicide application. Glyphosate is a very good tool for suppressing crested wheatgrass but it does not completely eradicate crested wheatgrass from well-established stands.

Native Grass Establishment

After the crested wheatgrass suppression, other species must be established to compete with weeds and any surviving crested wheatgrass plants or seedlings. Desired species usually must be planted as seed sources are often lacking. Estimates for seedling densities needed to establish a successful stand range from 40 to 80 seedlings m^{-2} at the end of the first season; most agree that 25 seedlings m^{-2} is the minimum density need for marginal stands (King et al. 1989, Morgan et al. 1995, Wark et al. 1995). The most important factors to consider are the method of planting, seed mix, and time of seeding.

Broadcasting

Broadcasting seeds is more risky than drilling and often requires more seed to establish new stands. Depredation by birds and rodents, poor soil-seed contact, and fluctuating moisture and temperature contribute to low germination and seedling survival rates. Six weeks after seeding, rodents and birds consumed 98% of broadcast wheatgrass seed mix in unprotected areas (Nelson et al. 1970). Water potential at the surface fluctuated more and reached much lower levels (-0.01 to -80 MPa) than at 2 cm below the soil surface (-0.01 to –7.2 MPa) (Nelson et al. 1970). On tilled seedbeds, broadcast seeds can be raked and packed down to reduce these problems but existing vegetation makes this unfeasible. Bakker et al. (1997) achieved stands of 145 seedlings m^{-2} by broadcasting blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.) seed into rototilled and herbicide treated plots at an upland site. Valley plots of the same treatment had only 35 seedlings m^{-2} and untreated broadcast seeded plots had less than 25 seedlings m^{-2}.

Small seeds such as blue grama may experience lesser predation rates than larger seeded species. If the seed is expensive, broadcasting is likely not cost effective due to the higher seeding rate needed to compensate for predation and lower germination rates.

Drilling

No-tillage drilling or sod-seeding is popular for range plantings and several manufacturers have developed drills for this purpose. No-till drills place the seed at the proper depth and packing wheels ensure good soil-seed contact (Baker et al. 1996). Gobin (1994) sod-seeded tall wheatgrass, northern wheatgrass, green needlegrass, and switchgrass into seedbeds treated with 2.5 L ha^{-1} glyphosate. Both sites produced acceptable stands of 60, 65, 32, and 130 seedlings m^{-2} respectively. Bakker et al. (1997), using a no-till drill, established moderately dense (90 and 45 seedlings m^{-2} at valley and upland sites respectively) stands of blue grama seedlings in old crested wheatgrass fields. At their valley site, establishment with the drill was three times greater than with broadcasting; though the opposite was true at their upland site. Low survival rates of seedlings in these plots may have been due to very low summer rainfall.

Timing

Seeding too soon after applying glyphosate can result in low establishment rates; waiting 12 to 14 days between herbicide application and seeding reduces the risk to seedlings while capturing spring moisture (Welty et al. 1983). Planting more than two weeks after herbicide application may result in reduced establishment due to competition from the recovering resident vegetation (Waddington and Schellenberg 1976). Cool season grasses can be seeded in the fall or spring though resulting stands can vary widely depending on the weather, location, and species. Six wheatgrass species drilled into chemically prepared seedbeds in October or March produced acceptable stands in July but by November, spring seeded plots had two to three times more seedlings than fall seeded plots (Nelson et al. 1970). In Saskatchewan, green needlegrass and crested wheatgrass had greater germination when planted in the fall and intermediate wheatgrass and Russian wildrye (*Psathyrostachys juncea* (Fisch.) Nevski) in spring (Kilcher and Looman 1983). A minimum of 60 cm of moist soil (approximately 10 cm of precipitation) is recommended for spring seeding (Holzworth et al. 2003). If spring moisture is insufficient, fall seeding is highly recommended.

Warm season grasses and forbs consistently produced acceptable stands when planted in spring. Fall seeding is not recommended for warm season grasses (McWilliams 1973, Ries and Hoffman 1996). Due to variable preferences of different species in native grass seed mixes and variable conditions between sites, both fall and spring planting times are recommended to determine the best planting time for a seed mix at a certain site.

Species Selection

A diverse community of native plants is necessary to fill niches and compete with surviving crested wheatgrass plants and seedlings. A mix of different growth forms and mid- and late-seral species is most effective at using resources and competing with undesirable species (Sheley et al. 1996). A diverse seed mix is needed to establish a diverse community and is more likely to contain some species that will survive adverse growing conditions.

Holzworth et al. (2003) list 18 native grass species and four native forb species that are suitable for planting in eastern Montana and commercially available. The USDA software VegSpec (2001) confirms that many of these are suitable for planting in silty clay loams in the 25 to 35 cm precipitation zone. Near Terry, Montana green needlegrass, western wheatgrass (*Pascopyrum smithii* (Rydb.) Löve), and needle-and-thread grass (*Stipa comata* Trin. & Rupr.) competed best with crested wheatgrass when planted in a mixture (McWilliams and vanCleve 1960). In both pastures, green needlegrass yielded 2.5 to 3.5 times more biomass than crested wheatgrass when planted at the same rate. Gobin (1994) planted switchgrass into glyphosate suppressed sod, resulting in seedling densities of 85 to 175 m^{-2}. Of 41 native species planted into glyphosate suppressed crested wheatgrass sod, Wilson and Gerry (1995) found seedlings of only seven species. Big bluestem (*Andropogon gerardii* var. *gerardii* Vitman), slender wheatgrass, yellow coneflower (*Ratibida columnifera* (Nutt.) Woot. and Standl.), and purple prairie clover (*Dalea purpurea* Vent.) had the greatest number of seedlings (93, 27, 11, and 6 seedlings in 60 m^2, respectively). Wheatgrasses, needlegrasses, and switchgrass are the most likely to establish and compete successfully with crested wheatgrass on silty range sites in eastern Montana.

Fertilizer

Nitrogen (N) fertilizer increased crested wheatgrass yields or cover, thus increasing competition with planted species (Bowes 1997, Gobin 1994; and Peat and Bowes 1995). In undisturbed plots, 0 g N m^{-2} treatments averaged 6 seedlings of planted species m^{-2} while 5 and 15 g nitrogen m^{-2} treatments averaged 1 and 0 seedlings m^{-2} respectively (Wilson and Gerry 1995). Adding fertilizer during the planting year may be detrimental to the establishment of seeded species.

Non-Target Species

Because glyphosate is non-selective and deactivated by contact with soil, any non-target species which are actively growing at the time of application are subject to damage, while species which are not active are not affected. Using carefully timed applications of glyphosate, the species composition may be altered without the need for seeding (Sampson and Moser 1982).

Non-target species can compete with seedlings as severely as crested wheatgrass (Bakker 1996). Species that are similar physiologically compete more strongly for water and nutrients than dissimilar species (R. Sheley, Pers. Comm. 2002). Non-target species that are present in the stand may compete with seedlings as much as unsuppressed crested wheatgrass.

Summary

No technique has proven to eliminate crested wheatgrass in a single application. As with many undesirable species, repeated treatments or combinations of treatments are necessary to reduce the population level. Herbicide application is the most effective method to reduce crested wheatgrass biomass and allow establishment of other plant species. Spring applied herbicide may shift the species composition of the stand toward warm season species in a mixed species stand. The best treatment appears to be glyphosate applied at 1.1 kg ha^{-1} in the spring when crested wheatgrass is 8 to 15 cm tall.

For chemically-prepared seedbeds, no-till drilling has a greater success rate than broadcasting. Drilling seeds 12 to 15 days after herbicide application avoids harmful effects of the herbicide to seedlings while utilizing high spring soil moisture. If spring moisture is insufficient (<60 cm moist soil) fall planting after a season of chemical fallow is recommended for cool season species. Individual species performance varies between site and year, so several species, which mimic the natural plant community for that site, should be included in a seed mix for better chances of a successful stand.

Objectives

The objectives of this project were to (1) evaluate the effects of spring-applied glyphosate on crested wheatgrass, seeded native species, and other, naturally occurring, species and (2) test seedling establishment of various native grass and forb species planted in glyphosate treated crested wheatgrass sod with a no-till drill. The null hypotheses were: (1) crested wheatgrass biomass would not be altered by applying glyphosate in the spring, (2) different seed mixes would not result in different seeded species biomass, and (3) non-target species biomass would not be altered by applying glyphosate in the spring and planting native species.

METHODS AND MATERIALS

Experiment sites were established at five locations in eastern and central Montana (Figure 1) to test treatment effects on a variety of soil, climate, and vegetation types. Conditions at these sites are representative of many decades-old crested wheatgrass fields the Bureau of Land Management (BLM) manages in Montana.

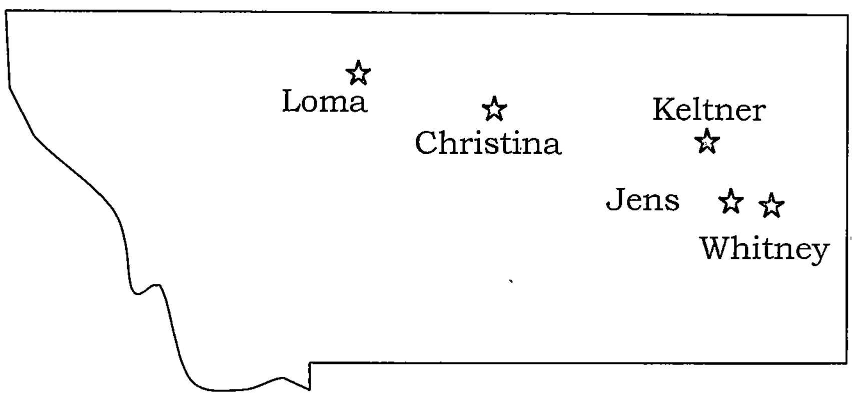

Figure 1. Map of study sites in Montana.

Sites

All sites were chosen on BLM land that had been planted to crested wheatgrass in the past 70 years. Four of the sites, Christina, Jens, Keltner, and Whitney, were former homesteads, planted with crested wheatgrass and returned to the BLM under the Bankhead-Jones Land Utilization Act during the drought of the 1930s. These four sites were also part of large grazing allotments prior to and during this study.

The fifth site, Loma, was traded to the BLM as part of a land exchange in 1988 and planted to crested wheatgrass at that time.

Christina (47° 24' N, 109° 17' W; elev. 1125 m) is located 10 km northeast of Christina, Montana on a level terrace over Arnell Creek. This is part of a large pasture and is surrounded by native vegetation. The soil type is Linnet clay loam, 2 to 8% slope (fine-montmorillonitic Usteric Argiboroll). The characteristic vegetation for this soil type is western and bluebunch (*Pseudoroegneria spicata* (Pursh) Scribn. & Smith) wheatgrasses, green needlegrass, and wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* (Nutt.) Beetle & Young) (USDA-NRCS 1988). The resident vegetation is crested wheatgrass with bluegrasses (*Poa* spp. L.), western wheatgrass, junegrass (*Koeleria macrantha* (Ledeb.) J. A. Schultes), and a wide variety of other grasses and forbs; clubmoss (*Selaginella densa* Rydb.) forms a dense groundcover in places.

Jens (46° 40' N, 105° 15' W; elev. 790 m) is located 13 km south of Terry, Montana, near the Jens Ranch on a flat terrace above the Powder River breaks. Plots are approximately 100 m from dryland grain fields. The soil type is Degrand loam 0 to 4% slope (fine-loamy over sandy-skeletal, mixed Aridic Argiboroll). Characteristic vegetation for this soil type is western and bluebunch wheatgrasses, green needlegrass, and needle-and-thread grass (USDA-NRCS 1996). The resident vegetation is dominated by crested wheatgrass with needle-and-thread grass, sand dropseed (*Sporobolus cryptandrus* (Torrey) A. Gray), red threeawn (*Aristida longiseta* Steudel), blue grama, Japanese brome (*Bromus japonicus* Thunb.), and green sagewort (*Artemisia dracunculus* L.).

Keltner (47° 00' N, 105° 37' W; elev. 855 m) is located 30 km northwest of Terry, near the Keltner Ranch on a flat bench over the Homestead reservoir. This site is part of a 5,500 ha pasture and is surrounded by native prairie. The soil type is Subwell-Peerless loam, 0 to 4% slope (loamy-skeletal, mixed Typic Haploboroll). Characteristic vegetation for this soil is western and bluebunch wheatgrasses, green needlegrass, and needle-and-thread grass (USDA-NRCS 1996). The resident vegetation is crested wheatgrass with needle-and-thread grass and silver sagebrush (*Artemisia cana* ssp. *cana* Pursh).

Loma (47° 53' N, 110° 32' W; elev. 825 m) is located 3 km southeast of Loma, Montana on a level terrace overlooking the Missouri River. This site is approximately 1 km downwind of dryland grain fields. The soil type is Fortbenton – Chinook fine sandy loam, 0 to 6% slope (fine-loamy, mixed Aridic Haploboroll). Characteristic vegetation for this soil type is prairie sandreed (*Calamovilfa longifolia* (Hook.) Scribn.), needle-and-thread grass, western wheatgrass and indian ricegrass (*Achnatherum hymenoides* (Roemer & J.A. Schultes) Barkworth) (USDA-NRCS 2001). The resident vegetation is crested wheatgrass and alfalfa with annual weeds such as cheatgrass (*Bromus tectorum* L.), kochia (*Kochia scoparia* (L.) Schrad.), russian thistle (*Salsola iberica* Sennen), and sunflower (*Helianthus annuus* L.). The stand at this site is much younger than the other sites. It was not grazed, but it was burned by the BLM in 1996 to remove accumulated fuels.

Whitney (46° 44' N, 105° 01' W; elev. 780 m) is located 22 km south of Fallon, Montana, in rolling hills between Whitney and O'Fallon Creeks, approximately 200 m from dryland grain fields. The soil type is Flowree silt loam, 0 to 6% slope (fine-silty, mixed Aridic Haploboroll). Characteristic vegetation for this soil is western and bluebunch wheatgrasses, green needlegrass, and needle-and-thread grass (USDA-NRCS 1996). The resident vegetation is crested wheatgrass with a large component of mixed blue grama and buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.), which covers approximately 50-60% of the site, bluegrasses, junegrass, needle-and-thread grass, and a wide variety of forbs.

Experimental Design

The initial experimental design at all sites was a randomized complete block with five treatments and four replications (Figure 2). The dimensions of each plot were 36 m x 36 m, surrounded by a 2 m wide buffer strip. Individual plots were experimental units.

The treatments were:

- Control,
- Spring application of glyphosate only,
- Spring application of glyphosate and plant with mixed native warm-season and cool-season grasses and forbs in spring 2002,
- Spring application of glyphosate and plant with mixed native cool-season grasses and forbs in spring 2002,
- Spring application of glyphosate and plant with mixed native cool-season grasses and forbs in fall 2002.

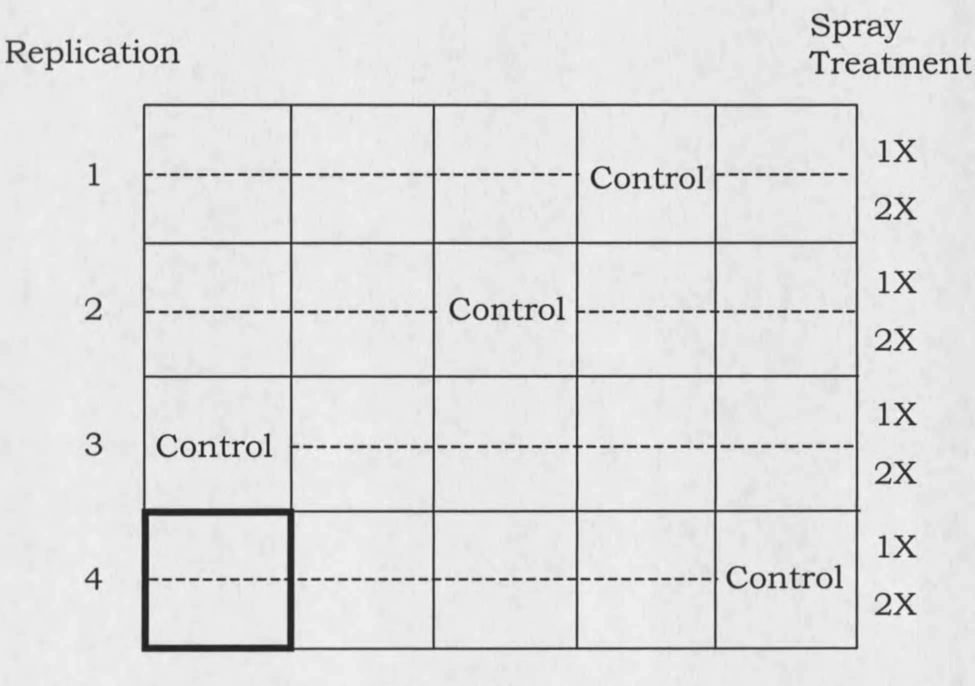

Figure 2. Site layout for experimental plots. Each 36 x 36 m plot (heavy outline) was assigned a planting treatment and planted in 2002. Plots were split into two 18 x 36 m spray treatment plots (dashed line), 2002 only (1X) and 2002 and 2003 (2X). Each replication contains all five planting treatments, randomly assigned.

Spray treatments

All plots except the control were treated with Roundup Ultra® (glyphosate) applied at 1.1 kg active ingredient (a.i.) ha^{-1} in early spring 2002 when the crested wheatgrass was 8 to 10 cm tall and most native species had not yet emerged. The glyphosate was applied by spray truck in 100 L of water per acre. An inert blue dye was used to mark treated areas and no site received precipitation within two days after treatment. Dates of treatment ranged from April 30 to May 30 (Table 2). Tordon® (picloram) was also applied to a small patch of leafy spurge (*Euphorbia esula* L.) within the Loma site in June 2002. This area was excluded from sampling.

Table 2. Treatment dates for glyphosate application (1.1 kg a.i. ha^{-1}) and planting seed mixes at five sites in eastern and central Montana.

Location	Glyphosate Application	Spring planting	Fall planting	Glyphosate Application
Christina	May 30, 2002	June 15, 2002	November 7, 2002	April 23, 2003
Jens	May 16, 2002	June 6, 2002	October 8, 2002	April 28, 2003
Keltner	May 17, 2002	June 7, 2002	October 8, 2002	April 28, 2003
Loma	April 30, 2002	May 14, 2002	October 22, 2002	Not Treated
Whitney	May 16, 2002	June 6, 2002	October 10, 2002	April 28, 2003

The non-control plots at Christina, Jens, Keltner, and Whitney were each split into two 18 x 36 m halves and herbicide was applied to one half again in April 2003, using the same method as in 2002, to control any regrowth of crested wheatgrass. Following this treatment, the 18 x 36 m split-plot was used as the experimental unit. Split-plot data is referred to as treated once (1X) for split-plots treated only in 2002 and treated twice (2X) for split-plots treated in 2002 and 2003. Loma was not retreated because of the very low kill rate in the first season.

Planting treatments

The spring-planted mixes were planted 14 to 21 days after the initial treatment (Table 2), at a depth of 2 cm, with a Truax™ no-till drill designed for native seed mixes. The sites were fenced with barbed wire to exclude cattle following the first planting. The cool season seed mix contained 100% cool season species and the warm season seed mix contained 32% cool season species and 68% warm season species by number of pure live seeds (Table 3). Seed mixes each contained eight grasses and one and two forbs. Selected species were either characteristic vegetation for tested soil types or fast-growing, adaptable species that could compete well with crested wheatgrass in a variety of climate conditions. The large number of species included reflects adaptation to different soil and climate types among sites.

The fall-planted cool season-mix was planted after air temperatures dropped below freezing during the day but before the ground froze. Planting dates ranged from October 8 through November 7 (Table 2).