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.

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
Bozeman, Montana

February, 2004

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.

Dr. Bok Sowell Bok Sowell 2-17-04
(Signature) Date

Approved for the Department of Animal and Range Sciences

Dr. Mike Tess M. W. Tess 2/17/04
(Signature) Date

Approved for the College of Graduate Studies

Dr. Bruce McLeod Bruce R. McLeod 3-3-04
(Signature) Date

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library.

Signature ____________________

Date 2-17-04

ACKNOWLEDGEMENTS

First I would like to thank the Bureau of Land Management offices in Montana for providing the funding and land for this project. I would also like to thank Todd Yeager and Adam Carr at the Miles City Field Office, and Fred Roberts at the Lewistown office for helping us in the field and providing us with information and tools.

Thanks to Paul Helland at the Prairie County Weed District for spraying all of my plots in Terry, and Al Lenz, Wade Warneke, Harley, and Jim Wood who helped me plant all of those seeds.

I would like to thank Drs. Sowell and Marlow for serving on my committee and a special thank you to Dr. Cash for all of the constructive comments during the thesis revision process.

Thanks to Mary and Sheila, who always made sure my crew and I got paid, and to Dave and the people at Enterprise for not getting mad when I got that truck stuck in the field. Thank you Kim for putting up with my requests for trucks and trailers.

Last I would like to thank Autumn, Arianne, Christy, Stephanie, Gary, and Patrick for spending many hours cutting plants with scissors.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES – CONTINUED

LIST OF FIGURES

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 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.

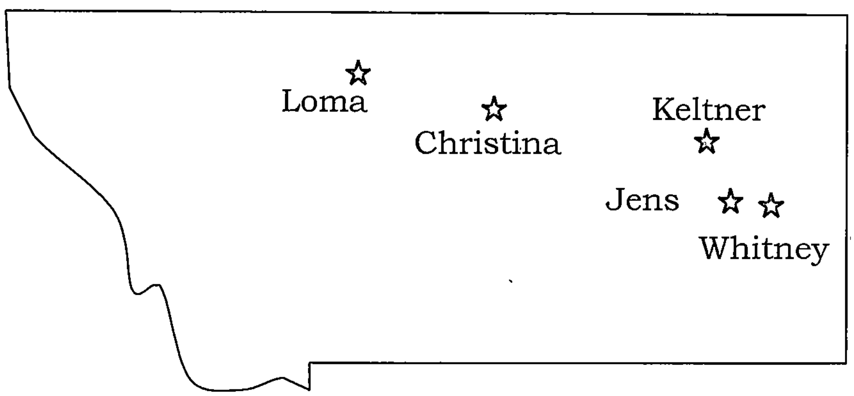

Figure 1. Map of study sites in Montana.

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.

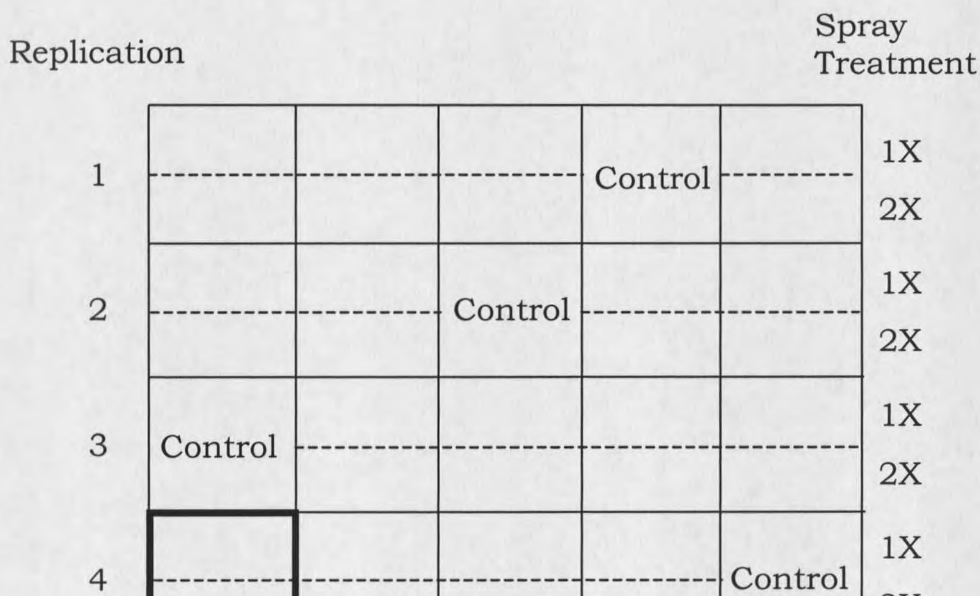

Figure 2. Site layout for experimental plots. Each 36 x 36 m plot (heavy outline) was assigned a planting treatment and planted in 2002. Plots were split into two 18 x 36 m spray treatment plots (dashed line), 2002 only (1X) and 2002 and 2003 (2X). Each replication contains all five planting treatments,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

Table 3. Composition of warm season and cool season seed mixes no-till seeded into glyphosate treated crested wheatgrass sod at five sites in eastern Montana.

Species	Percent by number [1]		Kg pure live seed ha^{-1}	
	Cool	Warm	Cool	Warm
Bluebunch wheatgrass cv. Secar *Pseudoroegneria spicata* (Pursh) Scribn. & Smith.	17.1%	8.3%	1.93	1.23
Slender wheatgrass cv. Pryor *Elymus trachycaulus* (Link) Gould ex Shinners	14.9%	14.7%	1.43	1.66
Thickspike wheatgrass cv. Critana *Elymus lanceolatus* (Scribner & J.G. Smith) Gould	13.1%	5.9%	1.09	0.68
Western wheatgrass cv. Rosana *Pascopyrum smithii* (Rydb.) A. Love	12.4%	3.0%	1.33	0.20
Prairie junegrass *Koeleria macrantha* (Ledeb.) J. A. Schultes [1]	3.1%	—	0.25	—
Sandberg's bluegrass *Poa secunda* J.S. Presl [2]	2.7%	—	0.17	—
Indian ricegrass cv. Rimrock *Achnatherum hymenoides* (Roemer & J.A. Schultes) Barkworth	23.2%	—	2.35	—
Green needlegrass cv. Lordom *Nassella viridula* (Trin.) Barkworth	12.3%	—	1.54	—
Lewis' blue flax cv. Appar *Linum lewisii* Pursh.	1.2%	—	0.15	—
Little bluestem cv. Camper *Schizachyrium scoparium (Michx.) Nash*	—	17.7%	—	2.00
Sideoats grama cv. Butte *Bouteloua curtipendula* (Michaux) Torrey	—	18.3%	—	1.19
Switchgrass cv. Forestberg *Panicum virgatum* L.	—	11.3%	—	1.05
Prairie sandreed *Calamovilfa longifolia* (Hook.) Scribn. [2]	—	13.2%	—	1.19
Purple prairie clover *Dalea purpurea* Vent. [2]	—	7.1%	—	0.38
Winterfat *Krascheninnikovia lanata* (Pursh) A.D.J. Meeuse & Smith [2]	—	0.5%	—	0.28
	Total kg ha^{-1}		10.23	9.86

[1] Pure live seeds.

[2] Common seed used.

All seeds purchased from Circle S Seeds, Three Forks, Montana.

Sampling

All vegetation sampling was conducted with 0.25 m^2 sampling frames randomly located in areas assigned to each sample number in each plot (Figure 3) so that sampling could be repeated in possible future studies. Sample patterns were altered in 2003 to reflect changes in plot shape.

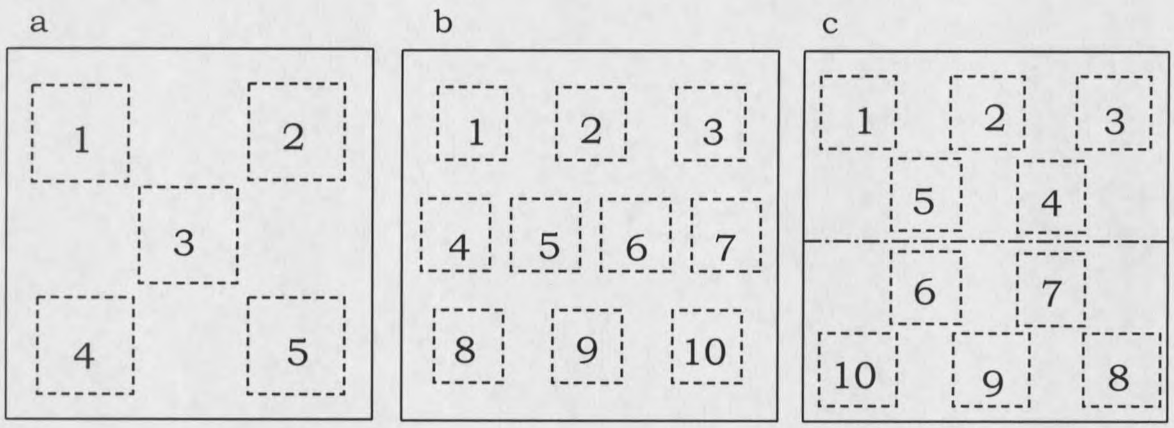

Figure 3. Sampling area layout for a) crested wheatgrass biomass in 2002, b) seedling counts in 2002, and c) split-plot biomass in2003.

Crested Wheatgrass Biomass 2002

In July 2002, at the approximate time of peak standing crop (Table 4), crested wheatgrass biomass samples were clipped at ground level at five locations per plot (Figure 3a). Samples were stored in brown paper bags, oven dried at 50°C for 48 hrs, and weighed. Sample weights for each plot converted to g m^{-2}.

Seedling Biomass Index 2002

In October 2002, at the end of the first growing season (Table 4), the seedlings were measured and counted using ten sample locations per plot (Figure 3b). To ensure that an equal amount of drill row was sampled, the sample frames were aligned with the drill rows. Each 50 x 50 cm frame covered three drill rows, so 150 cm of row are included in each sample. In each sample, seedlings were counted by species and average plant height was estimated for each species. Seedling data were later transformed by multiplying average height by number of seedlings to obtain a total height of each species per sample. This provided a rough estimate of biomass without the need for destructive sampling and is called the "biomass index". The total index for each plot was divided by 2.5, so the final units were cm (of plant height) m^{-2}.

Table 4. Sampling dates at five sites in eastern and central Montana.

Site	Peak Crop	End of Season	Final
Christina	July/August, 2002	October, 2002	August, 2003
Jens	July, 2002	October, 2002	August, 2003
Loma	July/August, 2002	October, 2002	August, 2003
Keltner	July, 2002	October, 2002	August, 2003
Whitney	July/August, 2002	October, 2002	August, 2003

All-Species Biomass 2003

In August 2003, the final biomass and density samples were taken (Table 4). Ten samples were clipped in each plot, five in each spray treatment, except control plots and all plots at Loma. Sample areas were rearranged to accommodate the split plot (Figure 3c) and the same pattern was used in control plots. As with previous sampling, the sample frames were aligned in planted plots to include 150 cm of drill row. The plants were counted, then clipped and stored in brown paper bags by species. All samples were oven dried for a minimum of 48 hrs at 50° C and weighed.

Crested wheatgrass samples were totalled for each plot and converted to g m^{-2}. The total of seeded species biomass samples for each plot was converted to g m^{-2}. Non-target biomass samples were converted to g m^{-2} and grouped by the following functional groups (modified from Tilman et al. 1997): native annual grasses, native cool season perennial grasses, native warm season perennial grasses, native annual forbs, native perennial forbs, native shrubs, cacti, clubmoss, introduced annual grasses, introduced perennial cool season grasses, introduced annual forbs, and introduced perennial forbs.

Soil samples were also obtained from each site in August 2003. Ten 15 cm deep cores were dug at random spots in each field and then mixed and analyzed for texture, nitrate (NO_3-N), phosphorus (P), potassium (K), organic matter (OM), and pH at the Soil Testing Laboratory at Montana State University.

For all plant and soil samples the following areas were avoided: seasonally wet areas, ant hills, animal burrows, cattle trail ruts, and areas not treated according to protocol (unsprayed or unplanted).

Diversity Index

Diversity indices were calculated for each split-plot and control using the Simpson Index. This index was used because it is more sensitive to the most dominant species, such as crested wheatgrass, than the Shannon-Wiener Index (Barbour et al. 1999). The formula used for the Simpson Index was $C = \Sigma(p_i)^2$ Where p_i is the proportion of each species based on biomass and C is dominance. To express the result as diversity instead of dominance, it was transformed to $D = 1 - C$ where D is diversity, with 1 being the most diverse and 0 being the least. All data is presented as D.

Statistical Analyses

2002

For sampling in the first year, the experimental unit was each 36 x 36 m plot. All sites contained 20 seeding treatment plots each in a randomized complete block of five treatments and four replications. The total number of plots across all sites was 100.

Site by treatment interactions for crested wheatgrass biomass and seeded species biomass index were tested with two-way ANOVA and found to be significant (P>0.10). Because of the interactions, data are presented by site for all variables. Within each site the following model was used for crested wheatgrass biomass and seedling biomass index: Y = general mean + planting treatment + replication + residual error. Residual error (12 d.f.) was used as the testing term. Mean separations were tested using the Student-Newman-Keuls test at P=0.10 when treatment differences were indicated by ANOVA.

<u>2003</u>

Experimental unit for split plots was each 18 x 36 m split-plot. Control plots at all sites and all plots at Loma were not split and each 36 x 36 m plot is the experimental unit. The total number of experimental units at each site in 2003 was 36 (32 treated split-plots and 4 control plots), except at Loma where the number was 20. Total number of experimental units across all sites was 164.

The following model was used for crested wheatgrass, seeded species, non-target biomass, and diversity index data within site: Y = general mean + planting treatment + spray treatment + spray x planting treatment interaction + replication + whole-plot error + split-plot error.

Split-plot error (11 d.f.) was the testing term for spray treatment differences and whole-plot error (12 d.f.) is the testing term for planting differences. The data were not normally distributed so they were rank-transformed prior to analysis (Abbott and Roundy 2003). When treatment differences were indicated by ANOVA, mean separations were tested pairwise with Dunn's test. Least square means are presented in tables for clarity.

For non-target data, functional groups that contained only a small number (N<6) of non-zero data within each site designated as trace (T) amounts. Trace amounts were included in totals and averages within site but were not analyzed individually.

Data are presented by site for all variables because site by treatment interactions for all 2003 biomass data were tested with two-way ANOVA on rank-transformed data and found to be significant (P<0.10). Control plots were excluded from tests for spray treatment interactions because they were not split. Spray treatment by planting treatment interactions, within site, are noted in data tables. For all biomass data, averages across planting treatments within site and averages across sites within spray and planting treatment are provided for review but were not tested due to interactions (P<0.10).

A P-value of 0.10 was chosen to compensate for the large variability within and between sites. Analyses were conducted with SigmaStat© 3.0 for Windows (2003) software from SPSS Inc.

RESULTS AND DISCUSSION

Weather and Soil

National Weather Service records indicated variation in the amount of precipitation at each site during the treatment year (2001 to 2002), from 11% more to 19% less than the 50 year average (Table 5).

Table 5. Annual precipitation (mm) at five sites in eastern and central Montana, Oct. 2001 through Sept. 2002 and Oct. 2002 through May 2003.

	2001-2002	50-year Average	Percent Difference	2002-2003	50-year Average	Percent Difference
Christina	423	380	11	194	195	-1
Jens	267	295	-2	152	117	30
Keltner	289	354	-19	169	163	4
Loma	288	322	-11	118	163	-27
Whitney	287	314	-9	162	150	8

The recommended soil moisture content for seeding in eastern Montana is 60 cm of moist soil (Holzworth et al. 2003), which is equivalent to about 10 cm of precipitation from October to the date of planting for loamy soils. From October to April, the study sites received 35 to 75% of the recommended precipitation (Figure 4). This lack of soil moisture combined with a late spring drought of 25 to 50 % below average precipitation probably caused the low seedling establishment rates at all sites.

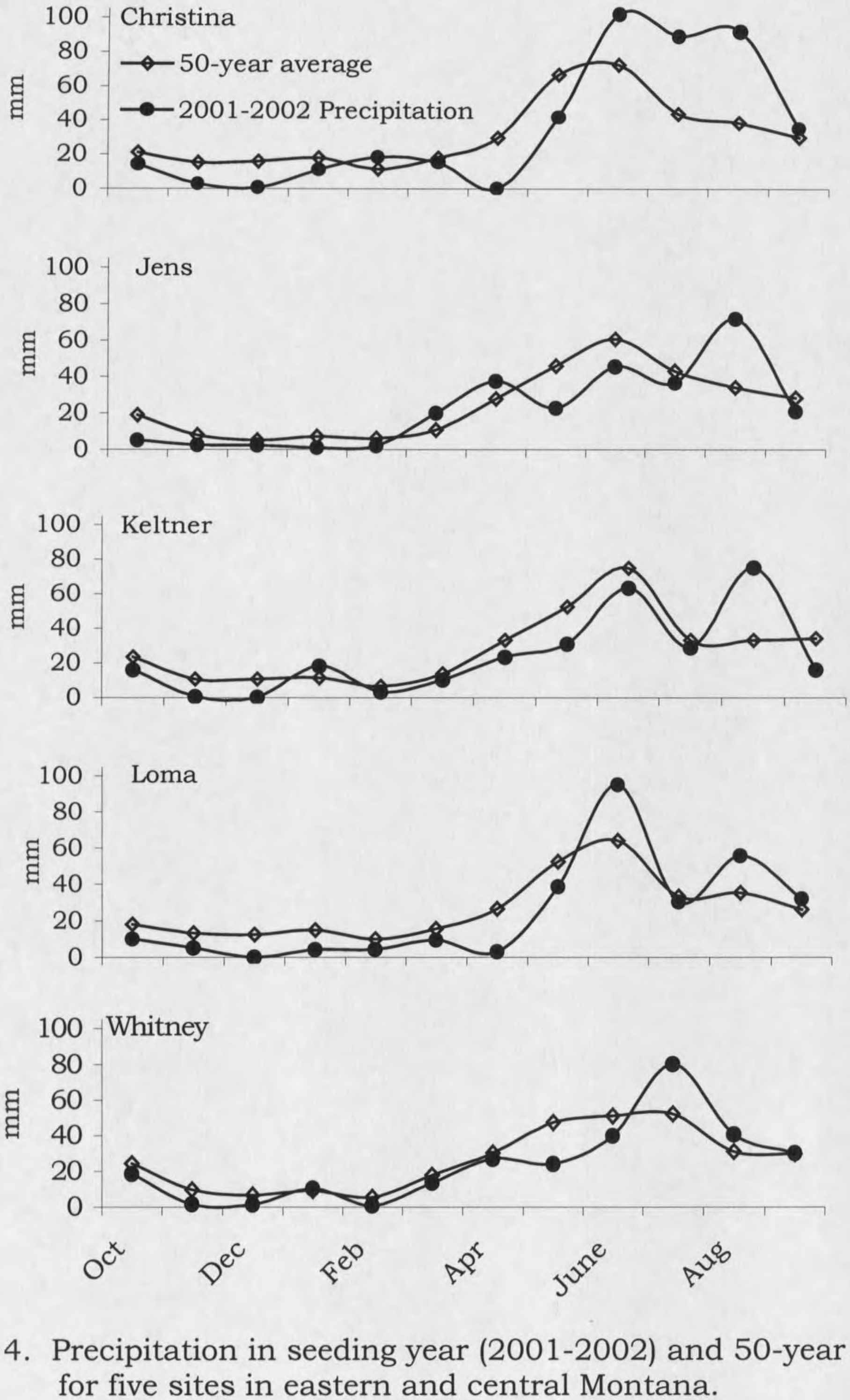

Figure 4. Precipitation in seeding year (2001-2002) and 50-year average for five sites in eastern and central Montana.

Much of the 2002 precipitation fell in late summer; Christina, Jens, and Keltner all received about twice the normal precipitation in August (Figure 4). All sites received 2 to 60 percent above average precipitation in March and April 2003, compensating somewhat for a dry winter.

Soil textures ranged from sandy to clay loams (Table 6) and closely matched descriptions from soil surveys. High levels of organic matter were found at Christina and Whitney, which have an abundance of shallow rooted, sod-forming species such as buffalograss and clubmoss. Buffalograss and blue grama tend to have higher soil organic matter than bunchgrasses to 15 cm depth on prairie soils (McHenry and Newell 1947).

Table 6. Soil properties at five sites in central and eastern Montana.

	Sand %	Silt %	Clay %	NO_3-N ppm	P ppm	K ppm	pH	OM %
Christina	32	37	31	1.6	11.1	538	6.8	4.17
Jens	54	33	13	0.8	4.2	204	7.3	1.35
Keltner	48	37	15	6.5	6.5	232	7.9	2.02
Loma	77	12	11	2.2	11.1	298	8.4	0.90
Whitney	22	53	25	3.2	12.6	344	6.1	5.22

Phosphorus and K levels were adequate to low at all sites (Table 6). Nitrate levels were very low at Christina, Jens, Loma, and Whitney, and low at Keltner (Jacobsen et al. 2003), which probably reduced seedling growth and establishment. Moisture and nitrogen were probably the most limiting factors for plant growth at all of our study sites.

Crested Wheatgrass

Crested wheatgrass biomass at all sites, except Loma, was reduced 30 to 100 % by applying glyphosate in 2002 (Table 7).

Table 7. 2002 crested wheatgrass biomass after spring application of glyphosate and planting with native seed mixes at five sites in eastern and central Montana.

Site	Christina	Jens	Keltner	Loma	Whitney	All Sites
	LS Means, $g\ m^{-2}$					
Control	15.4 b[1]	8.1 b	24.6 b	38.3 b	9.5 b	12.8
Spray Only	0.0 a	0.8 a	20.5 ab	37.9 b	5.0 a	9.0
Warm season mix	0.0 a	0.0 a	14.7 a	24.5 a	4.2 a	5.2
Cool season mix / Spring planted	0.0 a	2.8 a	15.1 a	27.5 ab	5.0 a	6.0
Cool season mix / Fall planted	0.0 a	0.0 a	18.1 ab	34.3 ab	4.1 a	7.8
Average [2]	0.0	0.9	17.1	31.1	4.6	7.0

[1] Treatment differences tested using one-way ANOVA and Student-Newman-Keuls mean separation. Means sharing a common letter within site are not different ($P<0.10$).

[2] Does not include control.

After one year of regrowth, in 1X split-plots, crested wheatgrass biomass was still reduced 48 to 94% versus the control, at all sites except Loma (Table 8, 1X data). These results are consistent with previous research using glyphosate in the spring. Gobin (1994) found a 77% average reduction in crested wheatgrass yields; Bakker et al. (1997) had a 26 to 70 % reduction in crested wheatgrass cover. Peat and Bowes (1995), by applying glyphosate when crested wheatgrass was 8 to 15 cm

Table 8. 2003 crested wheatgrass biomass after spring application of glyphosate in 2002 (1X) or 2002 and 2003 (2X) and seeding with native seed mixes at five sites in eastern and central Montana.

Site	Christina		Jens		Keltner		Loma	Whitney		All Sites	
	LS means, g m^{-2}										
Control	33.8 b[1]		65.3 b		116.3 c		91.7 a	78.0 b		91.7	
	1X	2X	1X	2X	1X	2X	1X	1X	2X	1X	2X
Spray Only	2.1 a	0.0 a	9.0 a	0.6 a	80.5 bc	7.0 a	98.6 a	7.4 a	0.0 a	39.5	3.0
Warm season mix	4.8 a	0.0 a	1.6 a	0.4 a	47.4 b	20.4 ab	102.1 a	43.1 ab	2.1 a	39.8	13.2
Cool season mix/ Spring planted	0.3 a	0.0 a	31.3 a	13.8 a	22.9 b	1.9 a	105.8 a	19.0 a	0.1 a	35.9	7.0
Cool season mix/ Fall planted	1.0 a	0.0 a	18.5 a	0.6 a	89.8 bc	2.2 a	78.3 a	30.8 ab	0.0 a	43.7	6.7
Average[2]	2.1	0.0	15.1	3.8	60.2	7.9	96.2	25.1	0.5	39.7	7.5

[1] Treatment differences tested using Kruskal-Wallis ANOVA on ranks and Dunn's pairwise mean separation. Means sharing a common letter within site are not different (P<0.10).

[2] Does not include control.

tall, achieved a 99% reduction in crested wheatgrass stem densities in the first year.

Applying glyphosate in both 2002 and 2003 (2X) at Keltner and Whitney reduced the biomass of crested wheatgrass, 87 and 98% respectively, versus applying only in 2002 (1X) (Table 8, $P<0.10$). Crested wheatgrass biomass at Loma after one year was not reduced by glyphosate application (Table 8, $P=0.83$). Glyphosate must be applied to green leaf tissue to be effective and the large amount of standing dead material at Loma probably limited the amount of glyphosate contacting the young shoots (Monsanto 1996). Grazing, mowing, or burning prior to application might have increased the effectiveness of glyphosate at this site.

When applied to 8 to 15 cm tall crested wheatgrass, a single application of glyphosate was a good tool for reducing the biomass of crested wheatgrass for two growing seasons; applying in consecutive years reduced the biomass further. Reducing the biomass of crested wheatgrass allowed other plants to increase in biomass, changing the dominant species in the community over the period of the study.

Seeded Species

Mortality rates among the cool season seedlings were visually estimated to be 5 to 100%, with great variability within sites. Desiccated seedlings were frequently found in the drill rows that had germinated and grown for several weeks before dying. May precipitation was 25 to 50% below average at all sites (Figure 4) and probably caused the low cool season establishment rates (Ries and Hofmann 1996).

Keltner was the only site with different seedling stands at the end of the first growing season, with a much larger biomass index for warm season seedlings (Table 9). Biomass index (total seedling height) at the end of the first growing season corresponded roughly with seedling biomass in the following season (Tables 9 and 10).

Table 9. 2002 biomass index [1] of planted-seedlings in plots treated with glyphosate and seeded with native species at five sites in eastern and central Montana.

Site	Christina	Jens [3]	Keltner	Loma	Whitney	All Sites
	----------	----------	LS means, $cm\ m^{-2}$	----------	----------	----------
Warm season mix[2]	0.5 a[2]	26.3 a	135.5 b	1.7 a	2.4 a	33.3
Cool season mix/ Spring planted	0.0 a	3.6 a	44.0 a	2.0 a	1.0 a	10.1
Average	0.2	14.9	89.7	1.9	1.7	21.7

[1] Obtained by multiplying average height by total number of seedlings.
[2] Treatment differences tested using one-way ANOVA and Student-Newman-Keuls mean separation. Means sharing a common letter within site are not different (P<0.10).
[3] All samples at Jens consisted of unidentifiable seedlings.

Table 10. 2003 planted-seedlings biomass after spring application of glyphosate in 2002 (1X) or 2002 and 2003 (2X) and seeding with native species at five sites in eastern and central Montana.

Site	Christina		Jens		Keltner[2]		Loma	Whitney		All Sites	
	1X	2X	1X	2X	1X	2X	1X	1X	2X	1X	2X
	LS means, $g\ m^{-2}$										
Warm season mix	0.1 a[1]	9.0 a	0.0 a	0.0 a	64.2 b	158.8 c	2.3 a	3.0 a	8.6 a	13.9	35.9
Cool season mix/ Spring planted	0.0 a	0.0 a	0.0 a	0.0 a	24.0 a	16.1 a	0.0 a	0.0 a	0.0 a	4.8	3.2
Cool season mix/ Fall planted	1.9 a	0.0 a	0.0 a	0.0 a	0.6 a	2.7 a	0.1 a	0.0 a	0.0 a	0.5	0.5
Average	0.5	2.2	0.0	0.0	29.6	59.2	0.8	1.0	2.9	6.4	13.1

[1] Treatment differences tested using Kruskal-Wallis ANOVA on ranks and Dunn's pairwise mean separation. Means sharing a common letter within site are not different (P<0.10).

[2] Spray x planting treatment interaction (P<0.01).

By August 2003, Jens had produced no planted seedlings and Loma, Christina, and Whitney each produced a small biomass of seedlings but the biomass was not different between treatments (Table 10, $P>0.10$).

The only site that had a large biomass of planted seedlings in 2003 was Keltner, where there was a larger biomass of warm season seedlings than cool season seedlings across spray treatments (Table 10, $P<0.10$). The dominance of warm season seedlings in the plantings is most likely due to the precipitation pattern during the treatment year, which was 126% above average during August and favored the growth of warm season species. Applying glyphosate twice (2X) increased the biomass of warm season seedlings (Table 10, $P=0.006$) versus applying once (1X). Glyphosate damage was visible on cool-season seedlings in the 2X plots but there were no differences between spray treatments site ($P=0.67$).

Native prairie restoration handbooks recommend >40 seedlings m^{-2} in the first year for successful stands and 25 seedlings m^{-2} for marginal stands (King et al. 1989, Wark et al. 1995). The average seedling density at Christina, Jens, Loma and Whitney was less than 1 m^{-2}, well below the recommended densities. The greatest seedling density in our study was in the warm season 2X planted plots at Keltner and averaged 25 seedlings m^{-2}, the minimum recommended density for a marginal seedling stand. Launchbaugh and Bement (1966) recommend 11 plants

m^{-2} for a successful adult stand, which warm season stands at Keltner exceeded. Although the seedling stands at Keltner initially failed to meet recommended seedling densities for successful stands, survival rate was likely high enough to result in a successful adult stand.

Table11. Composition of planted species seedlings across all planted treatments at the Keltner site in eastern Montana, August 2003.

Species	Biomass (g)	Percentage by biomass	Total number	Average biomass per plant (g)
Indian ricegrass	5.8 [1]	0.3	4	1.5
Green needlegrass	1.9	0.1	1	1.9
Slender wheatgrass	187.9	9.2	83	2.3
Little bluestem	52.0	2.5	27	1.9
Sideoats grama	12.3	0.6	5	2.5
Switchgrass	1463.9	71.5	155	9.4
Blue flax	261.6	12.8	20	13.1
Purple prairie clover	51.5	2.5	38	1.4
Unknown	11.7	0.6	9	1.3
Total	2148.7		542	4.0

[1] Total sampling area for planted plots = 30 m^2.

Warm season seedlings comprised approximately 77% of seedling biomass and 65% of seedling numbers at Keltner (Table 11). Switchgrass produced the largest number and biomass of seedlings although it was only 3.5% of the total seeds planted. At all sites, switchgrass comprised the largest proportion of the seedling biomass and numbers. Slender wheatgrass produced the largest number of cool season seedlings. Switchgrass and slender wheatgrass were also the least expensive seeds purchased for this project at $5 and $3 per kg of pure live seed. No seedlings were observed for: bluebunch wheatgrass, thickspike wheatgrass, Sandberg bluegrass, prairie junegrass, prairie sandreed, or winterfat. Switchgrass, little bluestem, purple prairie clover, and slender wheatgrass were the most successful species planted in this project.

Low nitrate in the soil may have had an impact on seedling establishment. The soil at Keltner contained 2 to 8 times as much nitrate as soil at other sites (Table 6) and Keltner had the largest seedling biomass (Table 10), composed primarily of switchgrass (Table 11). Sanderson and Reed (2000) and Hartnett (1993) suggest that available NO_3-N levels do not affect switchgrass growth but both studies applied NO_3-N levels much higher than those found on our study sites (4 to 20 times higher than at Keltner). Extremely low NO_3-N levels likely had a negative impact on switchgrass seedling growth and establishment.

At Christina, Jens, and Whitney, limited moisture and nitrate, and competition from non-target species likely caused the low seedling establishment rate. Greenhouse studies show that grass roots compete strongly for water and nitrogen even when both are in adequate supply (Haugland and Froud-Williams 1999). Seedling roots, being smaller, are at a competitive disadvantage against the roots of established plants (Bakker 1996). The roots of seedlings at Christina and Whitney were likely competing with native mat-forming species such as buffalograss and clubmoss. Seedlings at Loma were competing with the uncontrolled crested wheatgrass sod. Seedlings at Jens encountered both competition from weeds and consumption by grasshoppers, which can have a substantial impact on native grass populations (Quinn et al. 1993).

The combination of limited water and nitrate resources, competition with established plants, and damage by grasshoppers likely caused the poor seedling crop. Removal of species other than crested wheatgrass, such as weeds and mat-forming plants, may be necessary for establishing seeded species.

The expense of no-till drilling, about \$250 ha^{-1}, was much greater than the expense of glyphosate application, about \$80 ha^{-1}. Many of the native seeds purchased cost more than \$10 kg^{-1} and the average cost for both seed mixes was approximately \$95 ha^{-1}, though a more conservative seed mix may cost much less. Additionally, operating the drill and tractor cost roughly \$155 ha^{-1}. Considering the large expense and low success rate of the seedings on our project, no-till drilling was not cost effective. In crested wheatgrass stands that contain desired species, the large cost seeding may be avoidable with the careful application of glyphosate timed to reduce only the crested wheatgrass and encourage growth of desired species. In areas with large populations of undesirable species, conventional tillage and planting into stubble may be more successful than no-till drilling (Holzworth el al. 2003).

Non-target Species

Glyphosate application tended to shift dominance in crested wheatgrass stands toward warm season native grasses or weedy species, depending on the initial composition of the stand. The total biomass of non-target species was not altered by any treatment at Loma and Whitney (Table 12, $P>0.10$), but the species composition was altered. Glyphosate application at Christina, Jens, and Keltner increased non-target biomass in one or more treatments.

All treatments in the 1X split-plots produced more total non-target biomass than the control and the 2X split-plots at Christina (Table 12, $P<0.10$). Treating one year (1X) increased the biomass of native cool season perennial grasses and forbs in the following year, but treating consecutive years (2X) damaged them ($P<0.10$). Treating consecutive years also reduced the biomass of introduced perennial grasses, primarily Kentucky bluegrass (Table 13).

The biomass of annual plants at Jens increased in the glyphosate treated plots (Table 14, $P<0.10$). These weedy annuals consisted primarily of species that are commonly found in the nearby wheat fields; annual bromes and forbs. Sampson and Moser (1982) reported annual

Table 12. 2003 non-target species biomass after spring application of glyphosate in 2002 (1X) or 2002 and 2003 (2X) and seeding with native seed mixes at five sites in Eastern and Central Montana.

Site	Christina		Jens		Keltner		Loma	Whitney		All Sites	
	---LS means, $g\ m^{-2}$---										
Control	61.4 a[1]		9.0 a		6.4 a		10.7 a	69.0 a		29.5	
	1X	2X	1X	2X	1X	2X	1X	1X	2X	1X	2X
Spray Only	188.3 c	111.5 ab	94.9 b	87.5 b	166.8 b	59.4 a	29.6 a	123.2 a	117.8 a	102.1	76.1
Warm season mix	140.3 b	56.0 a	79.5 b	54.9 ab	35.5 a	37.2 a	13.8 a	116.5 a	109.8 a	62.2	51.8
Cool season mix/ Spring planted	164.7 b	63.1 a	43.9 ab	47.1 ab	52.5 a	21.4 a	30.1 a	103.2 a	65.7 a	70.3	38.4
Cool season mix/ Fall planted	125.2 b	81.9 a	54.0 ab	56.5 ab	36.3 a	48.5 a	29.7 a	104.2 a	97.7 a	59.4	58.8
Average[2]	154.6	78.1	68.1	61.5	72.8	41.6	25.8	111.8	97.8	73.5	56.3

[1] Treatment differences tested using Kruskal-Wallis ANOVA on ranks and Dunn's pairwise mean separation. Means sharing a common letter within site are not different (P<0.10).

[2] Does not include control.

weed invasion, primarily annuals bromes, on glyphosate treated plots in Nebraska. The same situation occurred at Loma though the effect was much less noticeable because of the large biomass of crested wheatgrass competing with the weeds (Table 16). Weed growth at Whitney was likely suppressed by competition from the dominant perennial, buffalograss (Table 17). In areas where there is a high potential for weed invasion, conventional tilling and/or non-selective herbicide may provide better growing conditions for seedlings (D. Cash, Pers. Comm. 2003)

Table 13. 2003 Biomass of non-target species by functional group following spring application of glyphosate in 2002 (1X) or 2002 and 2003 (2X) at Christina, Montana.

	Native Species			Introduced Species		
	Control	1X [2]	2X	Control	1X	2X
	LS Means, g m^{-2}					
Cool Season Perennial Grasses	18.4 a[1]	49.4 b	11.1 a	7.9 y	5.8 y	0.5 z
Warm Season Perennial Grasses	0.2 a	8.0 b	10.2 b	--	--	--
Annual Forbs	0.0 a	1.2 a	0.4 a	0.0	T [3]	0.0
Perennial Forbs	34.5 a	97.7 b	57.4 a	T	0.0	T
Shrubs	0.3 a	0.4 a	0.5 a	--	--	--
Total [4]	53.4	156.7	79.6	8.0	5.8	0.5

[1]Treatment differences tested using Kruskal-Wallis ANOVA on Ranks, and Dunn's pairwise. Means sharing a common letter within functional group are not different (P<0.10).

[2] Average of four planting treatments.

[3] T=Trace. More than 75% of samples did not contain plants in this group.

[4] Clubmoss cover was 44.8, 28.8, and 36.0 % in Control, 1X, and 2X respectively.

Table 14. 2003 Biomass of non-target species by functional group following spring application of glyphosate in 2002 (1X) or 2002 and 2003 (2X) at Jens, Montana.

	Native Species			Introduced Species		
	Control	1X [2]	2X	Control	1X	2X
	LS Means, $g\ m^{-2}$					
Annual Grasses	0.0 a[1]	5.0 b	0.3 a	0.5 z	12.5 y	10.0 y
Cool Season Perennial Grasses	0.4 a	1.8 a	0.5 a	--	--	--
Warm Season Perennial Grasses	4.1 a	17.4 a	29.9 b	--	--	--
Annual Forbs	0.0 a	17.6 b	6.2 a	0.0 z	3.9 z	9.2 y
Perennial Forbs	1.7 a	8.2 a	1.9 a	0.0	T [3]	T
Cacti	1.5 a	1.8 a	3.6 a	--	--	--
Total	7.7	51.8	42.4	0.5	16.6	19.2

[1]Treatment differences tested using Kruskal-Wallis ANOVA on Ranks, and Dunn's pairwise. Means sharing a common letter within functional group are not different (P<0.10).

[2] Average of four planting treatments. No difference between planting treatments (P<0.10)

[3] T=Trace. More than 75% of samples did not contain plants in this group.

Table 15. 2003 Biomass of non-target species by functional group following spring application of glyphosate in 2002 (1X) or 2002 and 2003 (2X) at Keltner, Montana.

	Native Species			Introduced Species		
	Control	1X [2]	2X	Control	1X	2X
	LS Means, $g\ m^{-2}$					
Annual Grasses	0.0	T [3]	T	0.1	0.0	0.0
Cool Season Perennial Grasses	3.4 a[1]	2.6 a	1.7 a	T	T	T
Warm Season Perennial Grasses	0.0 a	10.2 a	18.3 a	--	--	--
Annual Forbs	0.0 a	0.1 a	0.7 a	0.6 z	0.4 z	0.0 z
Perennial Forbs	2.6 a	48.7 b	9.9 a	T	0.0	T
Shrubs	0.0 a	2.6 a	4.6 a	--	--	--
Cacti	T	T	T	--	--	--
Total	6.0	64.4	35.3	0.8	0.4	0.0

[1]Treatment differences tested using Kruskal-Wallis ANOVA on Ranks, and Dunn's pairwise. Means sharing a common letter within functional group are not different (P<0.10).

[2] Average of four planting treatments. Planting x spray treatment interaction, P<0.001.

[3] T=Trace. More than 75% of samples did not contain plants in this group.

Table 16. 2003 Biomass of non-target species by functional group following spring application of glyphosate in 2002 (1X) or 2002 and 2003 (2X) at Loma, Montana.

	Native Species		Introduced Species	
	Control	1X [2]	Control	1X
	LS Means, g m^{-2}			
Cool Season Perennial Grasses	T [3]	T	T	T
Annual Forbs	T	T	0.0 z	0.4 z
Perennial Forbs	0.7 a[1]	0.4 a	2.2 z	9.0 z
Shrubs	T	T	--	--
Total	0.8	0.6	2.2	9.5

[1]Treatment differences tested using Kruskal-Wallis ANOVA on Ranks, and Dunn's pairwise. Means sharing a common letter within functional group are not different ($P<0.10$).

[2] Average of four planting treatments. No difference between planting treatments ($P<0.10$)

[3] T=Trace. More than 75% of samples did not contain plants in this group.

Table 17. 2003 Biomass of non-target species by functional group following spring application of glyphosate in 2002 (1X) or 2002 and 2003 (2X) at Whitney, Montana.

	Native Species			Introduced Species		
	Control	1X [2]	2X	Control	1X	2X
	LS Means, g m^{-2}					
Annual Grasses	0	T [3]	T	1.0 z	1.5 z	2.7 z
Cool Season Perennial Grasses	12.2 b[1]	9.3 b	2.6 a	--	--	--
Warm Season Perennial Grasses	32.5 a	85.7 b	69.5 b	--	--	--
Annual Forbs	3.0 a	7.5 a	2.8 a	T	T	T
Perennial Forbs	1.0 a	1.5 a	2.7 b	0.0 z	0.1 z	0.7 z
Total	48.7	104.0	77.7	1.1	1.7	3.5

[1]Treatment differences tested using Kruskal-Wallis ANOVA on Ranks, and Dunn's pairwise. Means sharing a common letter within functional group are not different ($P<0.10$).

[2] Average of four planting treatments. No difference between planting treatments ($P<0.10$)

[3] T=Trace. More than 75% of samples did not contain plants in this group.

The 2003 glyphosate application (2X) at all sites occurred slightly later in the growing season than the 2002 application (1X). Native cool season species had already broken dormancy in 2003 when glyphosate was applied and many were damaged at Christina, Keltner, and Jens (Tables 13, 14, and 15).

The 1X treatment of the spray-only treatment at Keltner had more total biomass of non-target species than all other treatments (Table 12, $P<0.10$), most of which was perennial forb biomass. The very high biomass of perennial forbs in the 1X spray-only treatment can be attributed to very large fringed sagewort plants, which weighed more than 1 kg each, that occurred in the sample areas. Fringed sagewort in the Northern Plains often increases in biomass after disturbance (Bai and Romo 1996). Applying glyphosate one year (1X), but not consecutive years (2X), increased the biomass of native perennial forbs at Keltner (Table 15, $P=0.065$). Most of the perennial forb biomass in the 1X plots was composed of cool season species, many of which were damaged by the 2003 glyphosate application.

Applying glyphosate in 2002 (1X) increased the biomass of native warm season grasses at Christina, Jens, Keltner, and Whitney (Tables 13, 14, 15, & 17, $P<0.10$). Applying glyphosate two years increased biomass of warm season species over applying one year at Christina, Jens, and Keltner; this agrees with the data from warm season seeded species at Keltner (Table 10).

The combination of increased warm season perennial grasses, decreased cool season perennial grasses, and increased annuals weeds agrees with results from spring applied glyphosate trials in Nebraska (Sampson and Moser 1982). Applying glyphosate in early spring shifts species compositions by increasing the biomass of warm season species and decreasing the biomass of cool season species.

Stands that are dominated by crested wheatgrass and contain native species can be shifted toward more native species and less crested wheatgrass by the proper application of glyphosate. To achieve the best results, glyphosate application must be done while crested wheatgrass is rapidly growing but desired species are still dormant. The competitive advantage gained by the desired species in the treatment year carries over into the following year and potentially many years. Stands that are prone to weed infestation are not recommended for this treatment and may require different herbicides or conventional tillage treatments.

Diversity Index

Species diversity can be increased by applying glyphosate to sites with low diversity. At Keltner and Jens, diversity in the control plots was low ($D \leq 0.20$) but increased in all treatment plots (Table 18, $P<0.10$). At

Table 18. 2003 Diversity index after spring application of glyphosate in 2002 (1X) or 2002 and 2003 (2X) and seeding with native seed mixes at five sites in Eastern and Central Montana.

Site	Christina		Jens		Keltner		Loma	Whitney		All Sites	
	LS means, D[1]										
Control	0.67 a[2]		0.20 a		0.09 a		0.12 a	0.66 a		0.35	
	1X	2X	1X	2X	1X	2X	1X	1X	2X	1X	2X
Spray Only	0.77 a	0.64 a	0.73 b	0.64 b	0.43 b	0.65 b	0.18 a	0.59 a	0.58 a	0.54	0.63
Warm season mix	0.66 a	0.61 a	0.73 b	0.65 b	0.70 b	0.44 b	0.20 a	0.74 a	0.53 a	0.61	0.56
Cool season mix/ Spring planted	0.69 a	0.78 a	0.55 b	0.60 b	0.72 b	0.62 b	0.11 a	0.65 a	0.60 a	0.54	0.65
Cool season mix/ Fall planted	0.71 a	0.69 a	0.77 b	0.60 b	0.48 b	0.60 b	0.32 a	0.61 a	0.63 a	0.58	0.63
Average[3]	0.71	0.68	0.69	0.63	0.58	0.58	0.20	0.65	0.59	0.62	0.57

[1] D=1-C. C is Simpson's index calculated from biomass. Least diverse equals zero, most equals one.

[2] Treatment differences tested using Kruskal-Wallis ANOVA on ranks and Dunn's pairwise mean separation. Means sharing a common letter within site are not different ($P<0.10$).

[3] Does not include control.

Keltner, much of the increase in diversity was due to planted species and native forbs. At Jens, most of the increase was due to annual weeds and warm season grasses. Reduction of crested wheatgrass on sites where it dominated opened areas for existing plants to expand and new plants to grow. At Loma, where glyphosate application was not effective at suppressing crested wheatgrass, diversity was low in control plots and treatment plots. At Christina and Whitney, diversity in control plots was high (D>0.65) and did not increase in any treatment plots. At sites where diversity was high in untreated areas, diversity was not increased by any treatment.

The input required to accomplish the same increase in diversity becomes much larger as diversity increases, so the same effort expended on communities of different initial diversity will have different results. At sites where diversity was initially low, and glyphosate was effective at reducing crested wheatgrass biomass, diversity was increased by all treatments, but there was little difference at sites which were initially more diverse. Determining whether these changes in diversity were temporary or lasting will require future observation.

Conclusions

Applying glyphosate was effective at reducing the biomass of crested wheatgrass and increasing the biomass of native species if applied at the correct stage of growth. Application should be done before desirable species emerge for most effective treatment. Additional glyphosate application one year after planting increased the biomass of warm season planted species, but damaged cool season planted species. Glyphosate application shifted the dominance in the stands toward native species or weedy species, depending on the plant and seedbank composition, by releasing those species from competition with the crested wheatgrass. Glyphosate application also increased the species diversity on sites with low initial diversity. The result of glyphosate application is highly dependent on the initial composition of the stand and the timing of application. These areas should be monitored in the future to determine the long-term effects of glyphosate application on crested wheatgrass and other species.

No-till seeding was generally not successful and limiting factors were likely lack of moisture and nitrogen. Because of the high cost of native seed and no-till drilling, this treatment is not recommended unless there is sufficient moisture (>60 cm moist soil) and nutrients in the soil at the time of seeding to support seedling growth. Switchgrass and slender wheatgrass were the most successful seeded species, making them good choices for planting projects where native species are desired.

Implications

Applying glyphosate is an effective tool for reducing the biomass of crested wheatgrass, but it can increase weedy species if sources of weed seeds, such as cultivated fields, are nearby. Applying glyphosate in areas occupied by mixed stands of native plants and crested wheatgrass can shift the dominance toward the native grasses and forbs, and increase species diversity, without the additional expense and effort of seeding, if the herbicide is applied only to crested wheatgrass and not native species. Seeding can be avoided when native species comprise a portion of the stand, weed sources are not near by, and glyphosate is applied to rapidly growing crested wheatgrass while native species are dormant.

LITERATURE CITED

Abbott, L.B., and B.A. Roundy. 2003. Available water influences field germination and recruitment of seeded grasses. J. Range Manage. 56:56-64.

Austin, D. D., P. J. Urness, and L. C. Fierro. 1983. Spring livestock grazing affects crested wheatgrass regrowth and winter use by mule deer. J. Range Manage. 36:589-593.

Bai, T., and J.T. Romo. 1996. Fringed sagebrush response to sward disturbances: seedling dynamics and plant growth. J. Range Manage. 49:228-233

Baker, C.J., K.E. Saxton and W.R. Ritchie. 1996. No-tillage seeding : science and practice. CAB International, Wallingford, Oxford, UK.

Bakker, J.D. 1996. Competition and the establishment of native grasses in crested wheatgrass fields. Masters thesis, Univ. of Regina, 70pp.

Bakker, J.D., J. Christian, S.D. Wilson and J. Waddington. 1997. Seeding blue grama in old crested wheatgrass fields in southwestern Saskatchewan . J. Range Manage. 50:156-159.

Barbour, M.G., J.H. Burk, W.D. Pitts, F.S. Gilliam, M.W. Schwartz. 1999. Terrestrial Plant Ecology – 3rd ed. Benjamin / Cummings, Menlo Park, CA. pp 191-193.

Bowes, G. 1997. Sod seeding forage to improve pasture: Summary of progress to 1994. Agriculture and Agri-Food Canada, Saskatoon Research Center. http://res2.agr.ca/saskatoon/brush_mgmt/sodseed94.html

Caldwell, M.M., J.H. Richards, D. A. Johnson, R. S. Nowak, and R. S. Dzurec. 1981. Coping with herbivory: photosynthetic capacity and resource allocation in two semiarid Agropyron bunchgrasses. Oecologia 50:14-24.

Gobin, S.M. 1994. Evaluation of grass establishment, development, and survival under sod-seeding conditions in the dry, sub-humid prairies. Masters Thesis, Univ. of Manitoba 195pp.

Hartnett, D.C. 1993. Regulation of clonal growth and dynamics of *Panicum virgatum* (Poaceae) in tallgrass prairie: Effects of neighbor removal and nutrient addition. Amer. J. Bot. 80:1114-1120.

Haugland E. and R.J. Froud-Williams. 1999. Improving grasslands: the influence of soil moisture and nitrogen fertilization on the establishment of seedlings. J. App. Ecol. 36:263-270.

Holechek, J. L. 1981. Crested wheatgrass. Rangelands. 3:237-250.

Holzworth, L., J. Mosley, D. Cash, D. Koch, and K.Crane. 2000. Dryland pastures in Montana and Wyoming: Species and cultivars, seeding techniques, and grazing management. Ext. Bull. 19. Mont. St. Univ. Ext. Ser., Bozeman, MT.

Hull, A. C., Jr., and G. J. Klomp. 1966. Longevity of crested wheatgrass in the sagebrush-grass type of southern Idaho. J. Range Manage. 19:5-11.

Jacobsen, J., G. Jackson, and C. Jones. 2003. Fertilizer guidelines for Montana crops. Ext. Bull. 161. Mont. St. Univ. Ext. Ser., Bozeman, MT.

Kilcher, M.R. and Looman, J. 1983. Comparative performance of some native and introduced grasses in southern Saskatchewan, Canada. J. Range. Manage. 36:654-657.

King, M.A., S.S. Waller, L.E. Moser, and J.L. Stubbendieck. 1989. Seedbed effects on grass establishment on abandoned Nebraska Sandhills cropland. J. Range Manage. 42:183-186.

Launchbaugh, J.L., R.E. Bement. 1966. A stand establishment survey of grass plantings in the Great Plains. Great Plains Agricultural Council Pub. no. 23. Univ. of Neb. Ag. Exp. Sta., Lincoln, NB.

Lodge, R.W. 1960. Effects of burning, cultivating and mowing on the yield and consumption of crested wheatgrass. J. Range Manage. 13:318-321.

Looman, R.E. and D.H. Heinrichs. 1973. Stability of crested wheatgrass pastures under long-term pasture use. Can. J. Plant Sci. 53:501- 506.

Lorenz, R.J. and G.A. Rogler. 1962. A comparison of methods of renovating old stands of crested wheatgrass. J. Range Manage. 15:215- 219.

McHenry J.R., and L.C. Newell. 1947. Influence of some perennial grasses on the organic matter content and structure of eastern Nebraska fine textured soils. J. Am. Soc. Agron. 39:981-984.

McWilliams, J.L. 1973. Effects of some cultural practices on grass production at Mandan, North Dakota. Tech. Bul. No. 1097. USDA, Washington, DC.

McWilliams, J.L. and P.E. vanCleve. 1960. A comparison of crested wheatgrass and native grass mixtures seeded on rangeland in eastern Montana. J. Range Manage. 13:91-94.

Monsanto Company. 1996. CRP-to-crops conversion: A guide for growers in the Northern Plains.

Morgan, J.P., D.R. Collicutt and J.D. Thompson. 1995. Restoring Canada's native prairies: A practical manual. Prairie Habitats, Argyle, Manitoba.

Nelson, J. R., A. M. Wilson, and C. J. Goebel. 1970. Factors influencing broadcast seeding in bunchgrass range. J. Range Manage. 23:163-170.

Peat, H.C. and G.G. Bowes. 1995. Direct seeding into crested wheatgrass: final report. Saskatchewan Agriculture and Food.

Quinn, M.A., P.S. Johnson, C.H. Butterfield, D.D.Walgenbach. 1993. Effect of grasshopper (Orthoptera: Acrididae) density and plant composition on growth and destruction of grasses. Env. Ento. 22:993-1002.

Reynolds, T. D., and C. H. Trost. 1980. The response of native vertebrate populations to crested wheatgrass planting and grazing sheep. J. Range Manage. 3:122-125.

Ries, R.E. and L. Hofmann. 1996. Perennial grass establishment in relationship to seeding dates in the northern great plains. J. Range Manage. 49:504-508.

Rogler, G. A. and R. J. Lorenz. 1983. Crested wheatgrass - early history in the United States. J. Range Manage. 36:91-93.

Romo, J.T., P.L. Grilz and L. Delanoy. 1994. Selective control of crested wheatgrass (*Agropyron cristatum* [L.] Gaertn. and *A. desertorum* Fisch.) in the northern Great Plains. Nat. Areas J. 14:308-309.

Sampson, J.F. and L.E. Moser. 1982. Sod-seeding perennial grasses into eastern Nebraska pastures. Agron. J. 74:1055-1060.

Sanderson, M.A. and R.L. Reed. 2000. Switchgrass growth and development: water, nitrogen, and plant density effects. J. Range Manage. 53:221-227.

Sheley, R. L., T. J. Svejcar, B. D. Maxwell. 1996. A theoretical framework for developing sucessional weed management strategies on rangeland. Weed Tech. 10:766-773.

Tilman, D., J. Knops, D. Wedin, P. Reich, M. Ritchie, E. Siemann. 1997. The Influence of Functional Diversity and Composition on Ecosystem Processes. Science. 277:1300-1302.

USDA. 2001. VegSpec Software. http://ironwood.itc.nrcs.usda.gov/Netdynamics/Vegspec/pages/HomeVegspec.htm

USDA-NRCS. 1988. Soil survey of Fergus county, Montana. Bozeman, MT.

USDA-NRCS. 1996. Soil survey of Prairie county, Montana. Bozeman, MT.

USDA-NRCS. 2001. Soil survey of Choteau county, Montana. Bozeman, MT.

Waddington, J. and M. P. Schellenberg. 1976. No-till seeding alfalfa in your old crested wheatgrass field. Research Newsletter: Semi-arid Prairie Agricultural Research Center. http://res2.agr.ca/swiftcurrent/news-nouvelles/960301.htm

Wark, D. B., W.R. Poole, R.G. Arnott, L.R. Moats, and L. Wetter. 1995. Revegetating with native grasses. Ducks Unlimited Canada, Stonewall, Manitoba.

Welty, L.E., P.F. Hensleigh, and V.R. Stewart. 1983. Methods for sod-seeding of small-seeded legumes and grasses. Ext. Bull. 752. Mont. St. Univ. Ext. Ser., Bozeman, MT.

Wilson, S.D., and A.G. Gerry. 1995. Strategies for mixed-grass prairie restoration: herbicide, tilling, and nitrogen manipulation. Rest. Ecol. 3: 290-298.