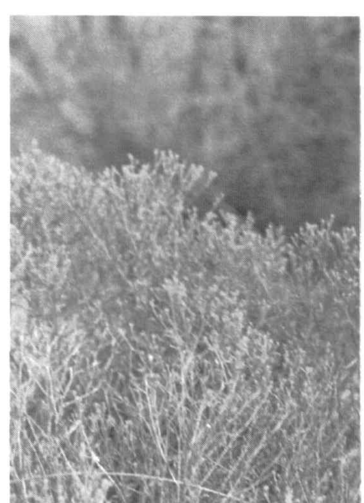
Revegetating Weed-Infested Rangeland: What We've Learned

James S. Jacobs, Michael F. Carpinelli, and Roger L. Sheley

Weed management efforts often focus on simply controlling weeds, with limited regard to the existing or resulting plant community. Because of environmental, ecological, and economic concerns, the appropriateness and effectiveness of rangeland weed management practices are being questioned. It has become clear that weed management decisions must consider these concerns. The development of future weed management practices must be based on our understanding of the biology and ecology of rangeland ecosystems.

Land-use objectives must be developed before rangeland weed management plans can be designed. Strictly killing weeds is an inadequate objective, especially for large-scale infestations. However, a generalized objective might be to develop a healthy plant community that is relatively weed-resistant, while meeting other land-use objectives, such as forage production, wildlife habitat development, or recreational land maintenance.

Highly degraded rangeland dominated by noxious weeds is often devoid of competitive desirable plants. On these sites, rangeland weed control is often short-lived because desirable species are not available to occupy niches opened by weed control procedures (James 1992, Sheley et al. 1996). Introducing and establishing competitive plants is essential for successful management of weed infestations and the restoration of desirable plant communities (Borman et al. 1991). However, revegetation often is not included in a weed management plan because it is costly and there is a high risk of failure. The process of revegetation must first identify the desirable plant community that meets management objectives, and then determine the seeding method, herbicide treatment, species to be seeded, and follow-up treatments to best achieve the desirable plant community.



The decision to revegetate must consider direct costs (seedbed preparation, seeds and seeding, follow-up management), indirect costs (risk of failure, non-use during establishment period), and benefits (increased forage, improved ecosystem function, soil conservation). Revegetation efforts should focus on sites and methods with the greatest potential for increasing net benefits in the shortest amount of time.

Rangeland revegetation is costly because current methods use agronomic practices. Typically, revegetation of weed-infested rangeland requires multiple entries. First, the site is disced in late fall to loosen the soil surface and encourage the germination of weed seeds in the seedbank. A few weeks later, a non-selective herbicide such as glyphosate (N-[phosphonomethyl] glycine) is applied to kill the newly establishing weeds. The combination of discing and herbicide application reduces the number of weed seeds in the seedbank and reduces weed competition the following spring. Soon after the herbicide is applied, fall-dormant grasses are seeded. The following spring, some of the remaining weed seeds in the seedbank and seeded grasses germinate and emerge. With adequate spring precipitation, both grass and weed seedlings survive. If grass seedlings survive until mid-summer, a reduced rate of 2,4-D ([2,4-dichlorophenoxy]acetic acid) or mowing is usually applied to weaken weeds and retard them from going to seed. Although revegetation with aggressive species has been shown to inhibit weed reinvasion (Borman et al. 1991), managers are reluctant to attempt it because of the high probability of failure and expense associated with this multiple-entry approach. Effective, single-entry methods must be developed for revegetation to be affordable and applicable to remote areas.

Failures in revegetation of weed-infested rangeland are usually caused by a combination of factors. The most important are insufficient soil moisture and intense weed competition. While some factors, such as climate, are beyond our control, we can use what we know about ecology to improve our success rate.

Seedling establishment is the most critical phase of revegetation (James 1992). Seedling establishment appears associated with the availability of safe sites (Harper et al. 1965, Wright et al. 1978) and the availability of seeds (Pickett et al. 1987). Rehabilitating weed-infested rangeland with desirable grasses typically fails, however, because of competition with weeds for safe sites during the initial stages of establishment (Borman et al. 1991, James 1992). In addition, density-dependent (e.g., competition) and density-independent factors (e.g., climate) interact to determine seedling survival during grass establishment in weed-infested rangeland (Velagala et al. 1997). Revegetation methods must address both of these factors to improve revegetation success.

Seeding Methods

Seedbed preparation and seeding depth affect seedling survival. The ideal seedbed for range seeding consists of pulverized surface soil with moderate amounts of mulch or plant residue, firm soil below seeding depth, and no residual competitive plants. Ideal seeding depths are about one-quarter inch (6 mm) for small seeds, and one-half inch (12 mm) for large seeds. Site conditions and cost will determine which seedbed preparation method is most appropriate.

Plowing and drilling. Plowing is the most effective method for preparing an ideal seedbed. However, it is costly and only practical on sites that are accessible to machinery and that have fertile, deep, and rock-free soils. Plowing not only removes competitive vegetation, it increases the establishment of seeded species. Seed placement is enhanced by plowing because the, roughening of the soil surface increases the number of safe sites. Plowing also loosens the upper layer of soil, thus facilitating root extension by establishing seedlings. In areas that can be farmed and intensively managed, plowing and drill-seeding has the best chance of insuring revegetation success (Figure 1). A typical three-year intensive revegetation plan includes plowing and seeding an annual hay crop in the first and second years, and replowing and seeding to a grass-legume mixture in the third year. The hay-cropping allows for the germination and removal of weeds from the seedbank while providing immediate financial return.

***Fig. 1.** Second years growth of "Luna" pubescent wheatgrass drill seeded after plowing.*

No-till-drill. The no-till-drill is a tractor pulled machine which opens a furrow in untilled ground, drops seeds in the furrow at a specified rate and depth, and then rolls the furrow closed (Figure 2). This method is the most practical and commonly used method on rangeland that is accessible to machinery because it is less expensive than tillage and because it reduces the risk of erosion associated with tillage. This is especially important in arid and semi-arid areas where tillage may exacerbate wind and water erosion. Because this method does not remove competitive plants, no-till-drill seeding is commonly preceded by a non-selective herbicide application.

***Fig. 2.** No-till drilling grass seeds on rangeland.*

Broadcast seeding. On sites that are inaccessible to machinery, site preparation is limited to removal of competitive plants via herbicide or fire. On small-scale projects, seeds are typically broadcast with a hand-held seed scattering device such as a cyclone spreader. Large-scale projects are usually helicopter seeded. Untilled soil usually lacks in safe sites, which may be countered by using a higher seeding rate than would be used on plowed ground. Covering seeds with soil or mulch improves germination and establishment. Other disadvantages to broadcast seeding are poor seed distribution, loss of seeds to rodents and birds, and slower establishment.

Alternative methods. Recent studies show that increasing the seeding rate above agronomic levels improves grass seedling establishment on weed-infested rangeland (Jacobs et al. 1996, Velagala 1996, Velagala et al. 1997). Alternative revegetation methods may be developed that use high seeding rates without increasing cost. For example, a strip-tilling/seeding method could seed desirable species at high densities on evenly spaced tilled strips. Successful seedling establishment would be increased because of the high seeding rate, and under proper management, the established species within the strips would spread naturally to the interstrip area. One way to facilitate the expansion of seeded species to the interstrips would be to first apply a herbicide to remove existing vegetation from the entire area prior to strip-tilling/seeding. Another way would be to use selective grazing of broadleaf species by sheep or goats to control the establishment of weeds in the interstrips. Similarly, islands of desirable plants could be established using high seeding densities so that the plant cover is dominated by desirable species. From these islands, desired species could spread naturally.

Herbicides

Herbicides provide an alternative to tillage for the removal of unwanted vegetation. Herbicides are often used where accessibility or erosion is a concern or tillage is cost-prohibitive. Herbicide selectivity, persistence, and timing of application are important considerations when deciding how to use herbicides for weed control in revegetation.

Non-selective herbicides. Most revegetation seedings are preceded by an application of a non-selective herbicide such as glyphosate. On rangeland where fall-dormant seedings are most practical, a late-season application of glyphosate can be used to eliminate fall-germinating annual weeds like cheatgrass (*Bromus tectorum* L.) and yellow starthistle (*Centaurea solstitialis* L.) that have emerged prior to the application. This may substantially reduce weed competition for early season moisture the following spring.

Broadleaf herbicides. Broadleaf herbicides are often used in rangeland revegetation because most weeds are broadleaved species and most seeded species are grasses. An advantage to some broadleaf herbicides is they have soil residual that will control broadleaf seedlings for up to 18 months. Picloram (4-amino-3,5,6trichloropicolinic acid) applied at a rate of 0.28 kg active ingredients per hectare (0.25 pounds per acre) provides control of many weeds for two or three years (Davis 1990). The combination of glyphosate and a residual broadleaf herbicide, such as picloram, may provide the best control of weeds for a one-pass revegetation procedure where only grasses are seeded. Broadleaved desirable species can be incorporated once the grasses are established and the residual effect of the herbicide is gone. Of course, where broadleaved desirable species are seeded in a one-pass operation, herbicide selection will be limited to a non-residual broadleaf herbicide such as 2-4, D or a non-selective, non-residual herbicide such as glyphosate.

Another important consideration is the ability of the desired species to withstand reinvasion.

Species Selection

Selection of desirable plant species is determined by intended use, soils, precipitation, temperature, and establishment characteristics. Another important consideration is the ability of the desired species to withstand reinvasion. For example, many aggressive introduced species and some native species have been shown to reduce leafy spurge infestations.

Intended use. The intended use of a revegetation site is important in determining what species to plant. If livestock grazing is the intended use, a perennial with high forage production is an obvious choice. One such species, crested wheatgrass (*Agropyron cristatum* L.), is a good spring pasture bunchgrass that can withstand a 60% defoliation without affecting its biomass production (Sheley and Larson 1997). Intermediate wheatgrass [*Elytriga intermedia* (Host) Nevski], a late-maturing grass, may be more appropriate if the intended use is summer pasture. Some areas such as state and federal parks mandate the use of native plants. Here, the plant community composition prior to weed invasion should be used as a guide to determine which species to seed.

Soils. Soil texture affects the establishment success of seeded species. While medium- to fine-textured soils are optimal for most species, some species do best in either sandy or clay soil. For example, Indian ricegrass [*Oryzopsis hymenoides* (R & S) Ricker] and pubescent wheatgrass [*Thinopyrum intermedium* spp *barulatum* (Schur) Barkw. D. R. Dewey] are well adapted to sandy soils, western wheatgrass (*Agropyron smithii* Rybd.) does well on clay soils, and most other species commonly used in revegetation do well on medium- to fine-textured soils (Table 1).

Precipitation. Seeded species need to be adapted to the precipitation level of the site. Crested wheatgrass and Russian wildrye [*Psathyrostachys juncea* (Fisch.) Nevski], (introduced species), and Indian ricegrass and bluebunch wheatgrass [*Pseudoroegneria spicata* (Prush.) Löve] (native species), are adapted to rangeland sites receiving 10 to 12 inches of annual precipitation. Pubescent wheatgrass and intermediate wheatgrass (introduced species), and green needlegrass (*Stipa viridula* Trin .) and western wheatgrass (native species), are adapted to 13 to15 inches of annual precipitation. Requirements for some other common revegetation species are summarized in Table 1.

Temperature. Temperature zones should be considered when designing seed mixes for revegetation. Warm season, C4 grasses (e.g., big [*Andropogon gerardii* Vitman] and little bluestem [*A. scoparius* Michx .]) are well adapted to the midwestern prairie. Cool season, C3 grasses (e.g., Idaho fescue [*Festuca idahoensis* Elmer] and bluebunch wheatgrass) are well adapted to mountain meadows of the Great Basin. Seed supply companies are good sources of information on the environmental requirements of revegetation species.

Establishment. Species differ in how fast and how well they establish. Crested and pubescent wheatgrasses are some of the easiest species to establish. Natives are generally slower and more difficult to establish. Seed size presents a trade-off between quick establishment and seed placement. Generally, larger seeds establish quickly, but do best if drill seeded or sown in tilled ground. Smaller seeds are more likely to find a safe site in untilled ground, but their limited amount of stored carbohydrates may inhibit establishment.

Designing seed mixes. Though grasses dominate rangeland and are the most commonly used species in revegetation, it is advantageous to use a combination species with differing growth forms when designing seed mixes. For example, seed mixtures of grasses with legumes improve the rate of microbial and soil structure recovery on conservation reserve program (CRP) land compared to grasses alone. In addition, a species mix of contrasting root growth forms (e.g., fibrous-rooted grasses and taprooted forbs) more efficiently fills niches and uses resources (Jacobs and Sheley 1999). In turn, where resource use is maximized, productivity is maximized. A diverse plant community is likely to be weed-resistant because few resources are available to a potential invader. Niche occupation can also be maximized by combining species that grow at different times of the year.

Seeding Rate

Increased seeding rates can alter the competitive interaction between desired species and weeds and can aid stand establishment. Increasing densities of intermediate wheatgrass from less than 1,000 seeds/m^2 to more than 1,000

Table 1. Characteristics of rangeland revegetation grass species.

Grass Species	Native/Intro	Growth form	Soil type	Precip. range (inches)	Establishment
Russian wildrye *Psathyrostachys juncea*	I	Bunchgrass	Silty-clay	<13	Difficult
Crested wheatgrass *Agropyron cristatum*	I	Bunchgrass	Silty-clay	<13	Easy
Siberian wheatgrass *Agropyron fragile* ssp. *sibericum*	I	Bunchgrass	Silty-clay	<13	Easy
Orchardgrass *Dactylis glomerata*	I	Bunchgrass	Silty-clay	<13	Easy
Bluebunch wheatgrass *Pseudoroeneria spicata* spp. *spicata*	N	Bunchgrass	Silty-clay	<13	Fair
Streambank wheatgrass *Elymus lanceolatus* spp. *riparium*	N	Rhizomatous	Silty-clay	<13	Fair
Thickspike wheatgrass *Elymus lanceolatus* spp. *lanceolatus*	N	Rhizomatous	Silty-clay	<13	Fair
Slender wheatgrass *Elymus trachycaulus* spp. *trachycaulus*	N	Bunchgrass	Silty-clay	<13	Quick
Bluegrass (big blue/canby) *Poa ampla/canbyi*	N	Rhizomatous	Shallow	<13	Easy
Indian ricegrass *Orizopsis hymenoides*	N	Bunchgrass	Sandy	<13	Easy
Sheep fescue *Festuca ovina*	N	Bunchgrass	Silty	<13	Easy
Basin wildrye *Leymus cinereus*	N	Rhizomatous	Silty-clay	<13	Slow
Pubescent wheatgrass *Elytrigia intermedia* spp. *trichophorum*	I	Rhizomatous	Sandy-silt	13–15	Easy
Beardless wheatgrass *Pseudoroegneria spicata* spp. *inermis*	N	Bunchgrass	Silty-clay	13–15	Fair
Western wheatgrass *Pascopyrum smithii*	N	Rhizomatous	Clay	13–15	Fair
Green needlgegrass *Stipa viridula*	N	Bunchgrass	Silty-clay	13–15	Slow
Prairie sandreed *Calamovilfa longifolia*	N	Rhizomatous	Sandy	13–15	Fair
Intermediate wheatgrass *Elytrigia intermedia* spp. *intermedia*	I	Rhizomatous	Silty-clay	14–15	Fair
Smooth bromegrass *Bromus inermis*	I	Rhizomatous	Silty-clay	14–15	Easy
Altai wildrye *Leymus angustus*	I	Rhizomatous	Saline	14–15	Slow
Meadow bromegrass *Bromus biebersteinii*	I	Rhizomatous	Silty-clay	15–18	Quick
Tall wheatgrass *Elytrigia elongata*	I	Bunchgrass	Saline	15–18	Fair
Timothy *Phleum pratense*	I	Bunchgrass	Silty-clay	15–18	Easy
Idaho fescue *Festuca idahoensis*	N	Bunchgrass	Sandy-silt	15–18	Slow

seeds/m^2 removed the effect of spotted knapweed on intermediate wheatgrass where interspecific interference occurred (Velagala et al. 1997). In a field study, Velagala (1996) found the greatest seedling establishment at the highest seeding rates, especially when combined with tillage. In that study, intermediate wheatgrass did not establish at a seeding rate of 500/m^2, which is the standard recommended seeding rate. The wide range of seeding rates studied by Velagala (1996) showed the potential for using seeding rates to enhance establishment.

Seed Treatments

Seed treatments may enhance the establishment phase of revegetation. Seed priming (Callan et al. 1990) is a treatment that initiates the germination process in a seed, allows it to continue to a certain point, and then suspends it. The primed seed is then ready to continue germination in the field when conditions are favorable. The idea behind seed priming is that the first seedling to capture resources has a competitive advantage (Harper 1980). Another advantage to priming is that dormancy is broken and germination is assured. This treatment has been shown to aid establishment under agricultural conditions, and it holds promise in rangeland revegetation.

Soil pathogens may accelerate the death of seeds and seedlings. Their role is best understood in crop species, though Tadros (1957) found fungal decomposition of seeds or very young seedlings in the soil could account, in part, for the different floristic composition of the natural vegetation. Seed fungicide treatments confer numerous advantages, including protection against diseases and pests and enhancement of growth (Powell and Mathrews 1988). A variety of these fungicides are commercially available for grass seeds and are intended to improve seedling establishment in reclamation projects (Taylor and Harmon 1990). Perennial grass seeds and seedlings can be protected from soil-borne organisms, including *Pythium* and *Rhizoctonia* spp., and many of the systemic fungicides provide the crowns and roots with a longer protection against *Fusarium* spp. and common root rots (Sprague 1950).

Putting It All Together

For revegetation of weed-infested rangeland to become more widely applicable to the various rangeland conditions, cost-effective and reliable methods need to be developed. Developing strategies that enhance our ability to cost-effectively establish desired plant communities may provide ranchers and land managers with a sustainable method for managing noxious weed-infested rangeland. Reducing the number of entries onto the land will reduce the cost of revegetation. Combining the factors discussed above to improve the success of establishing desirable species, and applying them in a single pass will be the most cost-effective and reliable way to revegetate rangeland. New equipment has made possible the simultaneous application of herbicides, tillage, and seeding as well as seeding using no-till methods.

For example, cost-effective and reliable revegetation of spotted knapweed/cheatgrass infested rangeland can be accomplished using a single pass system. This system involves applying 1/2 pint of Tordon® at the same time as seeding about 16 lbs/acre of 'Luna' pubescent wheatgrass using a no-till drill in the late-fall prior to the first hard frost. Tordon® provides 3 to 5 years of spotted knapweed control, and Luna pubescent wheatgrass is aggressive enough to compete with cheatgrass during the establishment period. Data suggest that successful stands can be established for about $40 per acre. 'Luna' pubescent wheatgrass has also been used in revegetation of leafy spurge infestations and can withstand re-invasion by leafy spurge for at least 8 years. The single pass system has also been marginally successful using the native, bluebunch wheatgrass.

Revegetation will be most successful if it works with successional processes. The three processes that influence the direction of succession are site availability, species availability, and species performance (Sheley et al. 1997). Combining these three processes in a revegetation application will provide the highest chance for long-term success. Tilling, herbicides, and intensive grazing create available safe sites. Species availability is accomplished by successfully selecting and distributing seeds. Herbicides, fertilizers, and selective grazing can be used to enhance desirable species performance.

Follow-up Management

Money and effort spent on revegetation will be wasted unless management practices are changed to favor the desirable species that were seeded. Rangelands are dynamic plant communities that are constantly being shaped by the process of succession. Successful revegetation requires that managers continuously monitor the land and adjust management practices to direct succession in a way that maintains a desirable plant community. For example, timing and frequency of cattle grazing can be adjusted to minimize the impact on grasses. Sheep or goats can be used to target broadleaved weed species. Biological control can be used to reduce the performance and seed production of weeds. Livestock given feed containing seeds of desirable species can be used as a tool to spread seeds. The possibilities are endless, and the success is dependent on the creativity and vigilance of the land manager.

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Authors are Post-Docoral Research Associate, Graduate Research Assistant, and Assistant Professor, Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, MT 59717.