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Abstract

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Large portions of the Great Basin become degraded and disturbed every day due to natural and human-induced causes. Some disturbed areas may recover naturally in time, but other areas may never recover naturally because invasive weeds establish quickly and prevent native plants from establishing. Invasive weeds can potentially spread into adjacent, healthy landscapes where they can threaten local biodiversity, alter nutrient and water cycling, diminish wildlife and livestock forage, and increase soil erosion and stream sedimentation. This publication provides an indepth, step-by-step guide to the processes and procedures of establishing desired plant species in the Great Basin ecosystem.

Keywords: invasive weeds, mulch, native plants, plant community, revegetation, seedbed, soil erosion.

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Preface

Major portions of the Great Basin become degraded and disturbed every day. Disturbances can be natural, such as floods and fires, or strictly human induced, such as roads and construction sites, utility line trenches, or improper grazing. These disturbed areas may recover naturally, but in some cases it may be many years before desired plants become established or recover. Conversely, some areas may never recover naturally because invasive weeds may become established and prevent native plants from establishing, growing, and reseeding. Furthermore, invasive weeds can potentially spread into adjacent, healthy landscapes where they threaten local biodiversity, alter nutrient and water cycling, diminish wildlife and livestock forage, and increase soil erosion and stream sedimentation.

Natural revegetation can be slow. Artificial revegetation of degraded or disturbed areas can speed or direct recovery and prevent soil erosion. Revegetation can also mitigate weed invasion or reestablishment and be useful where rangeland improvement is desired. Revegetation should only occur when necessary, as determined by the abundance of desired plants and seeds at the site.

This publication provides an indepth, step-by-step guide to the processes and procedures of establishing desired plant species in the Great Basin ecosystem. Detailed information for every situation is beyond the scope of this publication. Site-specific or expert advice should be obtained for species selection, establishment methods, and maintenance.

The authors' objective is to help improve the chances of revegetation success by providing practical and effective revegetation concepts and methods for establishing a desired plant community or returning sites to conditions as similar as practicable to the predegraded or predisturbed state. Depending on the situation, this process may entail many steps: salvaging resources, protecting key plant-community components, preparing the site appropriately, reducing weed interference, designing a proper seed mix, and seeding using the most effective method. Establishment should be monitored to quickly identify problems that could prevent or interfere with successful revegetation. Following establishment, proper vegetation management favoring the seeded species will be necessary. This includes maintaining the desired plant community for the long-term and deterring establishment of invasive weeds.

Contents

Step 1—Make a Goal Statement

Invasive weeds are considered one of the most serious problems facing land managers in the Great Basin. Aggressive, nonnative plants have the capacity to invade and affect the structure and function of ecosystems by displacing native plants and animals and altering nutrient and water cycles, fire return intervals, and energy flow.

Pest management was developed in cropping systems and, more often than not, focused on controlling pests. Today, range and wild land managers often focus on controlling weeds, with limited regard to the existing or resulting plant community. On rangeland, forestland, and roadsides, the effectiveness of various weed management strategies depends on how land is, and will be, used and managed. Invasive weeds must be considered when establishing revegetation goals. This implies that weed control alone is an inadequate objective, especially for large-scale infestations. A generalized objective for ecologically based weed management is to develop and maintain a healthy plant community while meeting other land use objectives, such as forage production, wildlife habitat development, or recreation land maintenance. Revegetation efforts are often a key component of ecologically based weed management.

Defining project goals and objectives is the most important step in planning a weed management or revegetation project. By setting goals and objectives, you will be able to determine if your management is working or if you should adapt your management practices. Goal statements should describe the desired conditions to be developed through management (figure 1). You should ask, "What do I want to accomplish?" Revegetation goal statements may include any of the following:

- Improve rangeland forage production or rehabilitate degraded or disturbed sites
- Reestablish vegetation quickly to minimize erosion
- Establish species that can minimize noxious weed invasion or reestablishment
- Restore a healthy plant community.

Setting objectives is useful because they provide a measurable link between goal statements and revegetation actions. To increase the likelihood of success, objectives should consider site characteristics, land use, economic constraints, realistic timeframes, and performance measures.

An example of a revegetation objective would be to:

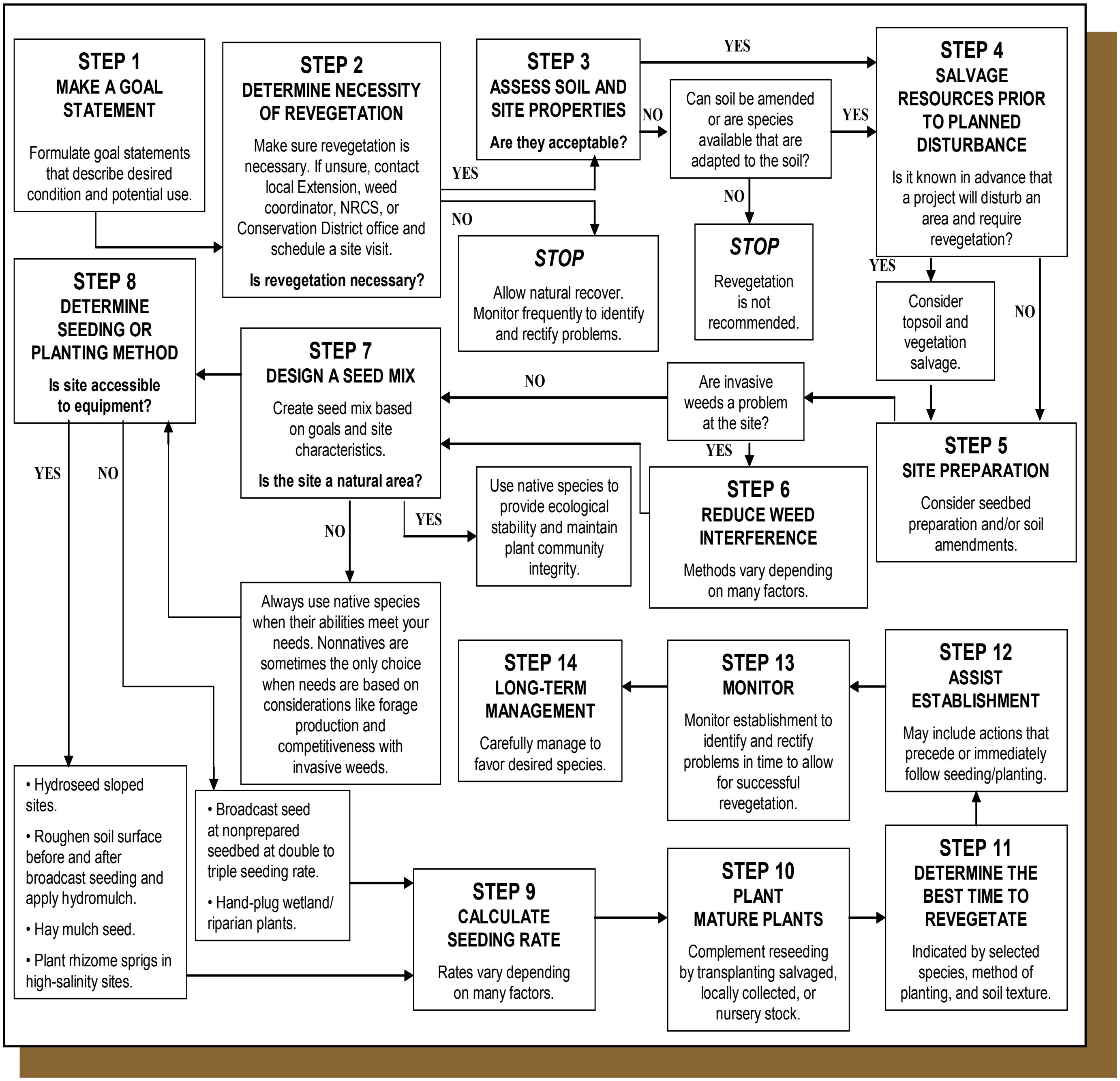
- reduce invasive weed canopy cover by 25 percent and increase native grass canopy cover by 10 percent 1 year after herbicide treatments and revegetation, and
- determine if adequate desired vegetation is present at the site to meet your revegetation goals and objectives.

Ecologically based weed management programs should focus on establishing and maintaining desired functional plant communities.

Step 2—Determine Necessity of Revegetation

Revegetation is expensive and should only be implemented when necessary. Determine if adequate desired vegetation is present at the degraded or disturbed site to assist the natural recovery process. Kotanen (1996) states revegetation should be constrained by the abundance and types of plants already available at the site. Determine the necessity of revegetation based on this advantage. Natural revegetation, therefore, may be the best option when desired plants are adequate at the site. Revegetation may be necessary, however, where rangeland improvement is desired to accommodate seasonal forage requirements and when quick groundcover is needed to mitigate erosion. Revegetation may also be necessary when desired plants

Figure 1. Checklist of Actions



are inadequate at the site to meet land use objectives, such as to minimize noxious weed invasion or restore healthy plant communities.

Rangeland improvement/forage production

Profitable ranching includes many components specific to the management of land, livestock, and resources. A year-round forage plan that satisfies livestock needs while maintaining the forage resource is essential. Often this includes seeded complementary pastures that supply nutritious forage when other sources are inadequate or unavailable during certain times of the year. Revegetating to meet this need and improve rangelands is often necessary.

Revegetation is not necessary on every degraded or disturbed site. Adequate desired vegetation may be present or nearby to assist the natural recovery process. Revegetation should be constrained by the abundance and types of propagules available at the disturbed site. As a result, natural regeneration may be the best option when desired plants are adequate within the site as propagules or whole plants.

Erosion control

Revegetation is often necessary to speed natural recovery. Disturbances that create bare slopes may require revegetation in combination with mulch, netting, or erosion control blankets to mitigate erosion while assisting germination and establishment. For example, wildfire-affected areas may require revegetation to speed recovery and prevent erosion. These areas include sites with severe burns, stream corridors, and slopes greater than 15 percent. (See "Revegetation After Wildfire.")

Desired plant introduction

Weed-infested sites with inadequate desired plant canopy cover, usually less than 30 percent when compared with the percentage of nondesired plant cover, may require revegetation with competitive plants to meet land management goals (figure 2). On these sites, weed control is often short-lived because desired species are not available to occupy niches opened by weed control.

Establishing competitive grasses, and eventually forbs (herbaceous, flowering plants), will be essential for successful long-term management of weed infestations and restoration of desired plant communities. Weed density should be significantly reduced to minimize competition with seeded species. This will require effective management for the first couple of years or longer to weaken an infestation and significantly reduce weed competition for light, water, and nutrient resources. Spot-treating weeds with herbicides or hand-pulling them should be done to protect and enhance the growth and vigor of native forbs, when possible. Unnecessary broadcast herbicide treatments will injure or permanently damage remaining native forbs. Once removed, forbs are difficult and expensive to reestablish. With effective, long-term weed management, weed-infested sites with more than 30 percent desired vegetation canopy cover do not usually require revegetation. When the cover of desired plants is adequate and weeds are controlled, desired grasses and forbs steadily occupy open niches made available by the removal of weeds.

Revegetation after wildfire

Revegetation is recommended in some burned areas after wildfire. Contact your local USDA Service Center to schedule a site visit and an assessment. Revegetating only when necessary will avoid suppressing the recovering native plant community and conserve limited resources.

Revegetation following wildfire depends on many factors, including:

- Burn severity—A high-severity fire can permanently damage desired plants and propagules, greatly limiting natural recovery. Runoff increases on slopes due to hydrophobic (water-repellent) soils and a lack of vegetation to absorb and use rainfall. Lack of competitive plants favors weed invasion.

Figure 2. Determining Canopy Cover of a Site

1. Obtain a hoop made from coated cable up to ½-inch thick (available at most farm and ranch supply outlets). Purchase 93 inches of cable and fasten the ends with a cable ferrule, clamped with a chisel or heavy screwdriver and hammer.

2. Randomly toss the hoop and let it land flat on the ground.

3. Visually estimate the percentage of ground covered by the canopy of desired vs. nondesired plants. (Do not count plants as this will give you density, not cover.) Overlapping canopies should be counted.

4. Repeat, randomly tossing the hoop throughout the site at least 10 times and estimating canopy cover of desired vs. nondesired plants.

5. Add the desired plant percentages and divide by 10 (or the number of times the hoop was tossed) to determine the *average desired plant canopy cover*.

Canopy cover is the area of ground covered by the vertical projection of the outermost perimeter of the natural spread of plant foliage. Small openings within the canopy are included.

Revegetation is usually recommended on high-severity burn sites, especially when slopes are present or weeds are a serious threat.

- Slope—Moderate severity burns on slopes greater than 15 percent usually require quick soil protection with annual ryegrass *(Lolium multiflorum)* or small grains. Stabilizing surface movement with weed-free hay mulch secured with netting or an organic tackifier is recommended. Soils benefit from cross-slope log erosion barriers or contour scarification when hydrophobic soils occur. Slash filter wind rows at toe slopes also improve soil stabilization.

- Proximity to drainages—Revegetate channels to mitigate serious erosion during increased flows and filter sedimentation from runoff. For quick temporary cover and protection, annual ryegrass at 10 pounds per acre or small, sterile grains at 20 pounds per acre are frequently seeded within 50 feet of drainage channels, regardless of burn severity. Installing temporary check structures in ephemeral drainages is also beneficial.

- Preburn invasive weed cover—Sites with inadequate desired plant canopy cover should be considered for revegetation regardless of burn severity. Revegetation will usually be necessary given moderate to high weed cover coupled with a lack of competitive plants and fire-produced disturbances such as increased nutrients and high light conditions.

- Exposed soil—New roads, firebreaks, embankments, and cut-and-fill slopes should be revegetated. During wildfire rehabilitation, replace soil that was pushed aside during firebreak development. By replacing this topsoil, revegetation may not be necessary if the soil contains an adequate amount of desired plant propagules. Replace this topsoil as soon as possible with a minimum number of machine passes.

Step 3—Assess Soil and Site Properties

It is important to determine if revegetation is likely to succeed or fail prior to implementation. Several soil properties provide a good indication of the likelihood of revegetation success. In some cases, problematic soil properties can be amended. For instance, soils with low organic matter can be amended—by adding compost. Highly acidic or highly alkaline soils can be amended with sulfur, peat, lime, or fertilizer. Practical alternatives to amending saline or alkaline soils can be used to seed with species adapted to these soil extremes.

Inland saltgrass *(Distichlis spicata)* is a native grass that grows well in saline areas. Altai wildrye *(Leymus angustus)* is a nonnative bunchgrass that is extremely saline-alkaline resistant. Slender wheatgrass *(Elymus trachycaulus)*, a native bunchgrass, and tall wheatgrass *(Thinopyrum ponticum)*, a nonnative bunchgrass, are tall species that are easily established and saline tolerant. Other plants that perform well in saline-alkaline sites are provided in tables 1–3.

Site characteristics

Site characteristics such as soil attributes, annual precipitation, soil moisture, temperature, and elevation need to be considered early during a revegetation project. This will help to define the goals and objectives of your desired plant community, appropriate species selection, and seeding method.

Soil attributes

Soil texture, which is determined by the size and distribution of the soil particles (sand, silt, and clay), is an important characteristic that can direct species selection. Most seeded species prefer medium- to fine-textured soils. However, Indian rice grass *(Achnatherum hymenoides)* is very drought tolerant and well adapted to sandy soils.

Loam soil texture is considered ideal and consists of 45 percent sand, 35 percent silt, and 20 percent clay. See “Manual Texturing” to learn how to measure soil texture (figure 3).

Determining the chemical properties of soil can also be helpful in directing or confirming species selection and identifying needed soil amendments. Soil chemistry can also indicate the suitability of the soil for plant survival and growth. If you are planning an especially challenging project, contact local experts and consider testing the soil for the following:

* Bulk density—This is a measure of how dense the soil is or how much mass is in a given volume of soil. The optimal range is 1.2 to 1.6 g/cm³. A bulk density within the optimal range ensures that the soil is not compacted and contains an adequate amount of pore space for water and gas exchange.

* pH—This is a measure of soil acidity (< 7.0) or alkalinity (> 7.0). The optimal range is 6.5 to 7.5. Alkaline soils are usually derived from chalk or limestone. Use species adapted to highly alkaline soils instead of attempting to amend the soil. Grasses, grass-like species, and forbs adapted to alkaline conditions are footnoted in tables 1–3.

* Electrical conductivity—This is a measure of soil salinity. The optimal range is 0 to 2 mmhos/cm soluble salts. Salinity is important because it influences the types of plants that will grow in an area. Grasses, grass-like species, and forbs adapted to saline conditions are footnoted in tables 1–3.

* Sodium adsorption ratio (SAR)—This is the proportion of sodium ions to the proportion of calcium plus magnesium ions in a saturated paste. The optimal range is < 6. When SAR is above 12, serious physical soil problems arise and plants have difficulty absorbing water.

* Organic matter—This is a measure of the percentage of organic material in the soil. The optimal range is > 3 percent. Organic matter increases soil porosity, water infiltrations, water-holding capacity, and nutrient reserves; and it improves soil structure. The addition of organic matter, such as compost, can increase soil microorganism development and thereby enhance the establishment of seeded species.

The decision index on the facing page will help assess soil conditions. Soil testing provides more accurate and site-specific information. Contact your county Extension agent or local USDA Service Center to assess soil conditions if your soil properties are outside the acceptable range.

Annual precipitation, soil moisture, temperature, and elevation

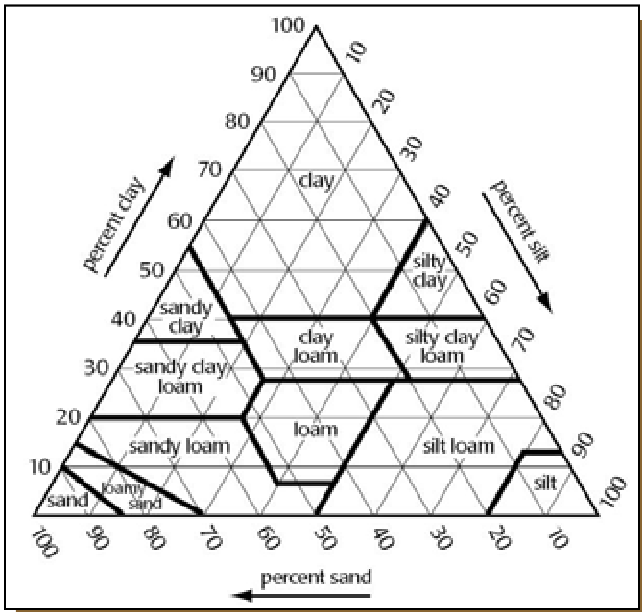
Revegetation projects should be adapted to the annual precipitation and soil moisture level of the site. Temperature zone and elevation of the site should also be considered. Obtain the USDA Plant Hardiness Zone Map from your local USDA Service Center to consider species survival, especially for shrubs, based on average minimum temperatures for winter.

Plant species selection and seeding methods should be suited to site conditions. For example, many species perform well on high soil moisture sites like stream bottoms or wet meadows subirrigated for at least part of the growing season. Subirrigated sites have a permanent water table within about 3.5 feet of the surface.

Step 4—Salvage Resources Prior to Planned Disturbances

Consider salvaging a portion of the vegetation from the site before disturbing it to avoid permanently losing this resource. This vegetation is already adapted to the site and when it is replaced, it may supplement the revegetation process. (See “Step 10—Plant Mature Plants.”) For instance, blocks of the existing native sod can be removed, stored, and replaced after construction work has been completed. As an alternative to salvaging whole plants, some seed companies offer onsite seed collection and custom growouts. For large or long-duration projects, the collected material

Figure 3. Manual Texturing



You can approximate the amount of sand, silt, and clay in soil by using a simple method called "manual texturing." The feel of the moist soil sample, when rubbed between the thumb and forefinger, determines the texture. If the sample is predominantly sand, it will feel coarse and gritty to the touch. If it is predominantly silt, it will feel smooth and slippery. And if it is predominantly clay, it will feel sticky and fine.

Soil texturing triangle illustrating the range in composition of sand, silt, and clay for each soil textural class. The dotted line depicts a loam soil that has 45% sand, 35% silt, and 20% clay content.

Decision Index

Soil parameter	Ideal condition	Acceptable range	My soil's properties	Are my soil's properties within the acceptable range: YES or NO?
Soil texture (sand, silt, clay)	Loam	Clay loam to sandy loam		
Bulk density (g soil/cm³)	1.4	1.2 – 1.6		
pH	6.5 – 7.5	< 8		
Electrical conductivity (mmhos/cm soluble salts)	0 – 2	< 8		
Soil adsorption ratio (SAR)	< 6	< 12		
Organic matter (% in soil)	> 3	> 2		

can be cultivated for a steady seed supply in subsequent years.

Also, consider salvaging weed-free topsoil from the site before a planned disturbance. Topsoil contains beneficial microorganisms (bacteria, fungi, protozoa, and so forth), earthworms, and insects, as well as living plant propagules such as seeds, plant fragments, and whole plants, which are valuable revegetation resources well adapted to the site. Biological activity in this zone cycles soil nutrients, increases nutrient availability, aerates the soil, maintains soil structure, and increases soil water-holding capacity. Reapplication of healthy topsoil enhances revegetation success and promotes establishment of a persistent vegetative cover. Topsoil that is damaged or unfit, for instance containing invasive weeds, should not be salvaged; instead, it should be removed and replaced with weed-free topsoil.

Avoid damaging topsoil by keeping the soil alive, protected, and weed-free until it can be returned to the site. Salvage the topsoil during the fall when it is moist (not wet) to avoid depressing potential recruitment of seeds present in the soil. Briefly store the topsoil in shallow piles less than 2 feet high, exposing as much soil to air as possible to avoid damaging microorganisms with anaerobic conditions. A study in Yellowstone National Park showed topsoil stripped and replaced within 90 days retained viable populations of mycorrhizae fungi, but topsoil stored over one winter lost most of its mycorrhizal propagules. If you must store topsoil longer than a few weeks, sow it with a protective, sterile cover crop, such as Regreen, a sterile hybrid cross between common wheat and tall wheatgrass *(Triticum aestivum x Thinopyrum ponticum)*, or triticale, a sterile hybrid cross between common wheat and cereal rye *(T. aestivum x Secale cereale)*. Monitor the stored topsoil often and remove invasive weeds.

When replacing topsoil to a site, do so with a minimum number of machine passes to prevent soil compaction. To avoid weed invasion or soil erosion, schedule topsoil replacement within a few days of revegetation. Spread the topsoil evenly over the surface, at least 6 inches deep. A study conducted at a mine site in northwest Colorado demonstrated that topsoil spread to this thickness was sufficient for the establishment and continued productivity of herbaceous vegetation. This study found deeper topsoil depths (12, 18, and 24 inches) were associated with plant communities dominated by grasses, while shallow topsoil depths supported more diverse plant communities with significantly greater forb production and shrub density.

Step 5—Site Preparation

Appropriate site preparation is important to ensure revegetation success. A variety of techniques and practices exists and the appropriateness will vary according to site conditions, seeding methods, species selections, available resources, and revegetation goals.

Sites with compacted soil

Soil consists of organic material, air spaces, and particles of sand, silt, and clay. A loss of soil structure from compaction, excessive tillage, or tillage when it is too wet, affects soil processes. Compaction limits the air exchange to roots and the ability of water to percolate through the soil. Compaction also limits the number of safe sites or areas suitable for seed germination and growth. Broadcasted seed will sit atop compacted soil where it will be vulnerable to wind, water, heat, and predation.

To improve soil structure and prepare a favorable seedbed for germination, compacted sites should be scarified or plowed. Scarification is a form of ripping that breaks up topsoil aggregates by raking the soil surface with ripper shanks that are pulled behind a tractor, grader, or bulldozer. In sites where the topsoil has been removed, ripping subsoils to a depth of 6 to 12 inches before adding topsoil is recommended.

Seedbed preparation

Compacted soil always requires seedbed preparation. The degree of seedbed preparation in other cases depends partly on the seeding method (see "Step 8—Determine a Seeding Method"), which is influenced by site accessibility, terrain, and seedbed characteristics. Seedbed preparation is usually not necessary when drill seeding, but is strongly recommended when broadcast seeding or hay mulch seeding.

The ideal seedbed contains adequate safe sites—being firm enough to allow good seed-to-soil contact, yet loose enough for the seed to sprout and penetrate the soil. Seedbed firmness is ideal when, walking across it, footprints remain that are about 4 inches deep.

A seedbed can be prepared through shallow chiseling, plowing, harrowing, or dragging small chains. Plowing loosens the upper layer of soil and increases the number of safe sites. Plowing should be carefully considered, as it may permanently damage desired vegetation and facilitate erosion on slopes or fine-textured soils. Also, carefully consider deep plowing on sites with invasive weeds. Deep plowing promotes nitrogen release, which favors heavy weed growth. If plowing is necessary, consider reducing nutrient availability to weeds by sowing a fast-growing cover crop.

Use spiked or toothed cultivating implements for harrowing and raking to uniformly roughen the soil surface. Small chains may function similarly. These operations are less destructive than plowing and are recommended when broadcast seeding into plant communities that still contain desired species. These methods can be used before and following broadcast seeding to break up crusts or to lightly cover seeds with soil. Light packing of the soil following broadcast seeding is beneficial for adequate seed-to-soil contact. The application of hydromulch following broadcast seeding may also prove beneficial.

Burned-area revegetation typically does not require seedbed preparation if the reseeding immediately

Photo 1. Ash produced by a fire provides an excellent seedbed. A fall-dormant broadcast seeding into the ash layer will cover and retain seeds until suitable conditions exist for germination the following spring.

follows a fire. Ash created by a fire can provide an excellent seedbed. A fall-dormant broadcast seeding into the ash will cover and retain seeds (photo 1). The moisture action over subsequent seasons will work the seeds into the soil while breaking down any hydrophobic soil layers. Frost heaving will also break down any ash crust layers that may have formed from fall rains before or after reseeding.

Soil amendments

Amendments are added to soils before or shortly after seeding to provide a better medium for plant growth. Soils with low organic matter can be amended with compost. Highly saline or alkaline soils can be amended with sulfur, peat, lime, or fertilizer, but planting species adapted to these soil extremes is recommended. Adding nitrogen can assist establishment in some cases. Adding soil microorganisms may also assist establishment.

Nitrogen fertilizers should only be used when soil tests reveal a gross deficiency. Adding nonessential nitrogen can reduce important mycorrhizal activity and encourage heavy weed growth. Rarely is nitrogen needed for native species, especially late-seral grasses such as bluebunch wheatgrass *(Pseudoroegneria spicata* ssp. *spicata)*. Late-seral grasses represent the climax of plant community succession (figure 4). These grasses have minimal nitrogen requirements, having evolved in low-nutrient environments. Reducing the amount of available nitrogen in the soil may increase late-seral grass establishment and decrease weed competition. For this reason, when seeding late-seral native grasses in moderate- or high-nitrogen sites, consider a low seeding rate (< 20 lb PLS/acre) with a sterile companion crop, such as Regreen, to sequester nitrogen. Nitrogen reduction will hinder the growth of invasive weeds and favor the establishment of late-seral seeded species. Companion crops also benefit seeded species by protecting seeds and soil from wind and water erosion, conserving soil moisture, moderating soil temperatures, and protecting seedlings.

Fertilizers may be necessary in mesic or moist sites when rapid growth and maximum production is desired with agronomic species such as tall fescue *(Lolium arundinacea)*. The high nitrogen requirements of this nonnative grass make it suitable to use in mixtures with nitrogen-fixing legumes such as alfalfa.

Soil microorganisms process mulch and dead plant material into a form available for plant uptake. Important microorganisms include bacteria, protozoa, and fungi. Mycorrhizal fungi contribute to plant growth and survival in degraded habitats. These fungi develop a beneficial relationship with plants and are known to improve the phosphorus uptake, drought tolerance, and pathogen resistance of host plants. These microorganisms also benefit nitrogen cycling, enhance the transport of water (improving drought resistance), and increase offspring quality, contributing to long-term reproductive success and fitness of the species. Mycorrhizal fungi can be naturally established by collecting the top litter layer from a local weed-free landscape, working it into the topsoil of the revegetation site, or planting shrubs that can capture wind-blown mycorrhizal spores. Mycorrhizal inoculation of locally collected or salvaged nitrogen-fixing plants or nursery stock may benefit a project. If determined to be beneficial, place inoculum below the seedling at transplant stage or dip bareroot stock in adhesive-treated inoculum.

Step 6—Reduce Weed Interference

Establishing seeded species in weed-infested sites depends on significant reduction of invasive weed competition or interference. When revegetating weed-infested sites, strategies to reduce weed competition will be necessary. These strategies include sequestering nutrients with cover crops, applying herbicide, maintaining biological control with insects, mowing, and/or grazing.

Reducing the availability of nutrients to weeds can reduce weed interference with seeded species, especially late-seral native grasses. Sites high in nitrogen favor fast-growing, invasive weeds, while

Figure 4. Understanding Succession to Direct Successful Revegetation

Early-seral species, like annual forbs, are usually the first plant types to grow on a disturbed site. In the absence of further disturbance, early-seral species are eventually replaced by later-seral species, such as perennial bunchgrasses, which are eventually replaced by shrubs and sometimes trees. This is plant succession. Invasive weeds often behave as early-seral species but can then interfere with or arrest succession before it reaches later seral stages that most landowners hope to attain. Developing and maintaining a plant community that is more advanced in the successional stage can help ensure invasive weeds do not become established in disturbed sites.

Revegetation can be most successful when it works with successional processes to direct plant communities toward a desired state. Three primary successional processes are:

1. **Site availability (disturbance)**—This plays a central role in initiating and altering successional pathways because it provides safe sites for new plants to establish. Site availability can be a natural disturbance or a designed disturbance, such as seedbed preparation or herbicide application, which removes weeds and opens small areas for occupation by desired species. Although site availability is important for the persistence of many native species, it can also promote weed invasion. Be sure to frequently monitor the site for new weeds.

2. **Species availability (colonization)**—This is the intentional alteration of seed availability by influencing seed banks of desired plants and weeds. Weed seed banks can be depleted through attrition if seed production is prevented or significantly reduced each growing season. Desired plant seed banks can be increased through revegetation.

3. **Species performance (competition)**—This is the manipulation of the relative growth and reproduction of plants in an attempt to shift the plant community in a desired direction. Domestic sheep can shift a plant community toward grasses by selectively grazing weedy forbs. By contrast, cattle can shift a plant community toward forbs and shrubs by selectively grazing grasses. Herbicide applications and biocontrols can increase desired plant performance through competitive weed removal, which makes soil resources more available to desired plants.

Consider these three processes when managing your land to increase your success in creating and maintaining a desired plant community.

sites low in nitrogen favor slow-growing, late-seral native grasses. Sowing cereal rye *(Secale cereale)*, an early-seral cover crop, dramatically lowered nitrogen and shifted the competitive advantage from spotted knapweed to bluebunch wheatgrass. Fast-growing cover crops sequester soil nitrogen and reduce weed interference by depriving weeds of some of this resource. To reduce nutrients at sites with high soil nitrogen, consider planting an early-seral cover crop the year before revegetating with native, late-seral grasses.

Managing infestations with mowing, herbicides, biocontrol, or grazing for a couple of years prior to seeding (or longer) may weaken an infestation. This will reduce weed interference and favor seeded species. In cases where forbs were planted, herbicides should be carefully applied only to nondesired weeds, or weeds should be hand-pulled to avoid damaging the seeded forb species. For instance, mowing spotted knapweed can be effective in reducing seed production and weakening an infestation. Mowing as a single management tool decreased spotted knapweed density by 85 percent after 2 years when mowing was done during the early bud stage. Integrating mowing with other management tools may further reduce weed density. Combining mowing with an appropriate herbicide applied 1 month after the last mowing cycle may be effective to reduce rapidly developing regrowth. Consider mowing and applying herbicide in a single, efficient entry with a wet-blade mower (appendix).

Another strategy to reduce weed interference is a fall-dormant no-till drilling operation preceded by a late-season, nonselective herbicide application such as glyphosate to remove weeds and invasive grasses such as cheatgrass *(Bromus tectorum)*. When cheatgrass is present, this strategy can substantially reduce competition for early-season moisture the following spring. When invasive forbs are dominant, a “single-entry” revegetation operation may be considered if the site is accessible to equipment (figure 5).

Young grass seedlings can be sensitive to many herbicides. Though herbicide recommendations are beyond the scope of this publication, some generalizations can be set forth. The application of bromoxynil at the three- or four-leaf grass stage enables early suppression of young broadleaf weeds while limiting injury to seeded grasses. The herbicide 2,4-D may be applied once the grass seedlings have reached the four- to six-leaf stage, or later. On the other hand, studies have demonstrated that the application of picloram at ½ to 1 pint per acre did not injure seeded grasses, even with the 2- to 3-year soil residual. Grass injury did occur, however, when picloram was applied at 2 quarts per acre. When treating noxious weeds with herbicides, take care to protect neighboring shrubs and forbs. Avoid broadcast herbicide treatments, unless necessary, as indicated by high weed density. Contact your local weed district or Extension office for herbicide recommendations and rates.

Biological control is the use of live natural enemies to reduce weed populations. Biological control agents, such as insects, stress the weeds and reduce overall plant production, but they do not kill the plants. Insect biocontrols are most effective when integrated with other weed control measures. Another type of biological control includes the use of grazing animals. This is a very effective method of weed control when performed at the proper time and intensity. Many invasive weeds provide good forage for sheep or goats, which have a dietary preference for forbs. Though grazing does not kill the weeds, at sufficient and proper intensity, it can effectively deplete seed production and root reserves to weaken an infestation. The competitive ability of the weeds is reduced and control treatments become more effective. An intensive grazing system that includes a minimum of two grazing periods per season, each followed by a rest period, is more effective than season-long grazing. Contact your local weed District or Extension office for biocontrol insects and grazing information.

Figure 5. “Single-Entry” Revegetation

Weed control is often short-lived in areas dominated by noxious weeds because desired species are not available to occupy niches opened by weed removal. Weed-infested sites that lack an adequate amount of desired species require revegetation for successful long-term weed management (Borman et al. 1991). However, revegetation of weed-infested sites is often expensive because of the number of attempts required for success and the number of field entries needed to maximize the potential for seedling establishment.

The revegetation of weed-infested sites has customarily required the following multiple entries:

1. The site is tilled in late fall to loosen the soil and encourage germination of weed seeds.

2. A few weeks later, a nonselective herbicide is applied to control newly emerging weeds. The combination of tillage and herbicide reduces the density of weed seeds the following spring.

3. Following the herbicide application, fall dormant grasses are seeded with a no-till drill.

4. The following spring, the remaining weed seeds and seeded grasses germinate and emerge. With adequate spring precipitation, both weed and grass seedlings survive. If grass seedlings survive until midsummer, a broadleaf herbicide, such as 2,4-D, is applied to reduce weed interference.

Successful revegetation of weed-infested sites can be expensive when multiple entries are required. By contrast, a “single-entry” approach can direct cost-effective and reliable revegetation. In one late-fall field entry, a residual broadleaf herbicide can be applied at the same time grasses are seeded with a no-till drill.

One study combined eight herbicide treatments and three grass species at sites in Montana infested with spotted knapweed. The best revegetation success resulted with a fall application of picloram at ½ or 1 pint per acre with ‘Luna’ pubescent wheatgrass *(Elytrigia intermedia* ssp. *trichophorum)* as the seeded species. This cost-effective and reliable “single-entry” strategy may be considered as a major component of many sustainable weed management programs.

Step 7—Design a Seed Mix

When selecting species, varieties or cultivars, choose those most appropriate to the revegetation goals and environmental conditions of the site. These include soil attributes, annual precipitation and temperature, and elevation. These factors vary across different parts of the revegetation area.

The selection and use of native species is strongly encouraged. This will promote ecologic stability and plant community integrity and reduce the risk of seeding an aggressive or invasive species. Native species recommendations for ecoregions throughout the Great Basin and potential seed vendors can be found at The Native Seed Network website (http://www.nativeseednetwork.org). The USDA-NRCS Plants Database at http://plants.usda.gov/ provides plant profiles with synonyms, classifications, distribution maps, images, and additional sources and references for plant species. This USDA website also hosts VegSpec (http://vegspec.nrcs.usda.gov/vegSpec/index.jsp), a Web-based decision support system that assists land managers in planning and designing revegetation projects. VegSpec utilizes soil, plant, and climate data to select plant species that are site-specifically adapted, suitable for the selected practice, and appropriate for the goals and objectives of the revegetation project. Other helpful sources are the Intermountain Planting Guide published by USDA-ARS and Restoring Western Ranges and Wildlands, a three-volume guide published by USDA Forest Service, Rocky Mountain Research Station. Contact your local USDA Service Center or Extension agent to assist in the design of a proper seed mix that also addresses species compatibility.

Take care to ensure adequate species diversity in a revegetation seed mix. Experts advise several species of grasses should be seeded, but not more than five, to cover the range of site conditions and increase the chances of revegetation success. When developing a mix, consider species compatibility, as seedling vigor varies by species. Some vigorous species develop rapidly, often at the expense of other species in the mix. For instance, nonnative tall wheatgrass *(Elytrigia elongata)* should be seeded alone, as it will completely dominate a site after 4 or 5 years. Species characterized by slow-developing, nonaggressive seedlings, such as nonnative Russian wildrye *(Psathyrostachys juncea)* and tall fescue, should also be seeded alone. Birdsfoot trefoil *(Lotus corniculatus)*, an introduced legume, is intolerant of competition from other plants and performs best alone. Unless the site is to be grazed, avoid mixing tall-growing grasses with shade-intolerant legumes such as birdsfoot trefoil. Such grasses can suppress legume performance.

When purchasing seeds, make sure they are weed-free. Purchase certified seeds to improve quality and establishment. (Bags of such seed bear blue "certified seed" tags.) Certification guarantees that the seeds have the same genetic potential to perform in the field as the breeder seeds variety when it was first released for production. For instance, when purchasing certified "Tegmar" intermediate wheatgrass *(Thinopyrum intermedium)*, you will have dwarf intermediate wheatgrass plants to meet your revegetation goals. Avoid purchasing preformulated wildflower seed mixes. One study found that 19 packets of wildflower seed mixes contained anywhere from 3 to 13 invasive plant species. Instead, buy certified wildflower seeds species by species and make sure they are native to the region.

Recent interest in native wild land seed collections and the need for well-adapted native species for reclamation has prompted a seed certification class for wild land collections. The "Source Identified Class" verifies the species and origin of wild land seed harvests. Seeds with yellow "certified seed" tags are harvested following approved guidelines and procedures.

The tags confirm the species and origin of the harvest. Wild land seeds may have long-term resiliency, but large quantities must often be collected to offset low seed viability. Custom collecting by commercial harvesters is possible and may be necessary for large projects when a site-specific seed

Figure 6. Native vs. Nonnative Species Selection

Many land managers interested in wide adaptability, easy establishment, forage production, and competitiveness with invasive weeds are shifting from seeding introduced grasses, such as crested wheatgrass *(Agropyron cristatum)*, to native species to restore the genetic and ecological integrity of ecosystems. This shift is based on social values that are changing as a result of advances in ecological knowledge.

The benefits of using natives include:

- **Erosion control**—Many native grasses and forbs have rhizomes or deep and fibrous root systems that help prevent soil erosion. Blue wildrye can provide quick erosion control. Streambank and thickspike wheatgrass, both strongly rhizomatous grasses with excellent seedling vigor, are also used for erosion control.

- **Vegetation management**—Short-growing native grasses, such as Idaho fescue, Sandberg bluegrass, Canby bluegrass, and 'Nortran' tufted hairgrass, reduce roadside mowing maintenance.

- **Aesthetics**—Native plants establish a more natural setting.

- **Ecological resiliency**—Natives represent a genetic product of an environment and are adapted to the means and extremes of an area. Natives can maintain excellent performance under a variety of conditions and demonstrate fewer "boom-or-bust" responses to environmental extremes than some introduced species.

For areas currently dominated by the annual grasses cheatgrass and medusahead, a multistep process may be required. In "assisted succession," the site is first revegetated with a competitive nonnative grass like crested wheatgrass to reestablish the perennial nature of the site. The second step may occur several years later and involve reintroducing native species while chemically or mechanically controlling the crested wheatgrass. This process may require more time and additional resources, but it may also increase your chances of success.

Data from Harper-Lore 2000 and Cox and Anderson 2004.

is desired or when preferred species are not commercially available.

A list of selected species based on desired season of use is provided in table 4. Recommended native grass species are listed in table 1. A list of nonnative grasses for typical projects is provided in table 2, and selected forb and shrub species are listed in table 3. Selection of species should be determined by revegetation goals and objectives and specific conditions of the site (figure 6).

Revegetation goals

Improve rangeland forage production or rehabilitate degraded or disturbed areas

Rangeland improvement—Many native and nonnative species are appropriate for rangeland improvement. Mixtures of species with differing palatability are usually not recommended, as some will be overgrazed while others are underutilized. For instance, needle-and-thread grass *(Hesperostipa comata)* is preferred less often than other grasses. The relatively low palatability of tall wheatgrass makes it necessary to have pastures fenced separately, giving livestock no forage alternative. Seed mixtures should be designed with special attention paid to species compatibility to avoid reversion to a few species over time. A series of dryland pastures may be an option with one or more of them planted to spring-grazed species and others planted to summer or fall species.

Consider pasture management and the ability of the species to supply forage when needed, and then design the mix to accommodate seasonal forage requirements. For instance, winterfat *(Krascheninnikovia lanata)* is one of the most valuable plants for maintaining animal weight on the winter range. Bitterbrush *(Purshia tridentata)* provides high year-round nutrition, but maximum plant performance is maintained when it is used as winter forage.

Forage production can be enhanced with a mixture of productive cool-season grasses and a deep-rooted legume. This mix produces more high-quality forage than grass alone. For instance, orchardgrass *(Dactylis glomerata)* alone will yield an average of 1 to 2 tons of hay per acre, but it can yield a maximum of 2 to 3 tons per acre when grown with clover or alfalfa. In addition, the palatability and nutritive value of tall fescue are improved when it is grown with a legume. To avoid bloat, replace alfalfa with low-bloat legumes, such as native vetches or sainfoin *(Onobrychis viciaefolia)*, cicer milkvetch *(Astragalus cicer)*, or birdsfoot trefoil. Following seeding, and if appropriate to the site, consider planting shrubs that can add vertical strata to the ecosystem and eventually enhance soil fertility, reduce evapotranspiration, increase nutrient cycling, add organic matter from litterfall, and further improve soil structure. The presence of shrubs may increase the productivity of associated grasses as compared with shrub-free grass stands.

Natural area rehabilitation—Areas not managed for forage production, such as natural areas, should be seeded with native species. Seeding nonnative species is not recommended because they may inhibit native community recovery and alter the diversity of local plant communities.

When designing a seed mix for natural areas, including wetlands, use the local native landscape as a reference for species selection. Local wild land collected seed could be considered because the seeds may be well adapted to local conditions. Depending on growing conditions of the current year, wild land seeds can sometimes have low viability. For instance, germination tests of Indian ricegrass *(Achnatherum hymenoides)* revealed that more than half the seeds lacked a developed embryo and were not capable of germination. Collecting large quantities of seeds is necessary to compensate for low viability. This can increase collection time and costs unless volunteers are available.

Roadside rehabilitation—Roadside soil often has low fertility and depleted biological activities because of nutrient-poor construction subsoil fill. These soil conditions reduce the establishment and persistence of vegetative stands and limit revegetation success. To increase long-term success, healthy topsoil should be added to supply nutrients, plant propagules, and mycorrhizal inocula when current soils are unfit or missing from roadsides. If appropriate, plan a topsoil salvage and replacement operation.

After construction is complete, a quick application of seed is usually necessary given the likelihood of rapid invasive weed establishment along roadsides. In addition, the freshly scarified, roughened surface provides an excellent seedbed.

When selecting plant materials, consider the species' ability to adapt to the site, rapidly establish, and self-perpetuate. Whenever practicable, select and distribute native species based on ecological criteria. Native grasses, such as Idaho fescue *(Festuca idahoensis)*, Sandberg's bluegrass *(Poa secunda)*, and 'Nortran' tufted hairgrass, are short-growing and can significantly reduce costly roadside mowing maintenance (photo 2). Also, consider the species' ability to minimize soil erosion and tolerate disturbance. Rhizomatous species with extensive root systems are a good choice. For instance, streambank and thickspike wheatgrass *(Elymus lanceolatus and E. macrourus,* respectively) are strongly rhizomatous with excellent seedling vigor. They are frequently used for road-

Photo 2. Idaho fescue is a native, low-growing bunchgrass. Its short stature reduces the need for mowing maintenance, making it a good choice for roadsides.

side erosion control but are tall in stature and may require regular mowing.

When revegetating roadsides, it is difficult to recreate a native community in its entirety. It is still valuable, however, to use species that are major components of the targeted community type. Morrison (2000) states that species that are dominant, prevalent (that is, typically occurring most abundantly), and have a "visual essence" (that is, having some unique, visually important trait within the community) should be included. Implementing integrated roadside vegetation management (IRVM) practices that favor the seeded species is essential to long-term roadside revegetation success.

Quickly reestablish vegetation to minimize erosion

Sloped landscapes and drainages should be seeded with soil-stabilizing species. Quick-establishing annuals provide immediate protection, but only for a year. Italian ryegrass *(Lolium perenne)* or small grains establish very quickly to provide rapid protection and are nonpersistent. Regreen is a sterile hybrid cross of common wheat and tall wheatgrass that reduces wind and water erosion, establishes quickly, and is nonpersistent. Canada wildrye *(Elymus canadensis)* and slender wheatgrass are quick-establishing native grasses that are often included in seed mixtures for rapid establishment of protective cover. Slender wheatgrass *(Elymus trachycaulus)* is often seeded at 20 to 40 percent of the seed mix for wildfire rehabilitation.

Rhizomatous grasses and grass-like plants are ideal for erosion control because of their extensive networks of soil-stabilizing underground stems and roots. 'Critana' thickspike wheatgrass, a native rhizomatous cultivar with very strong seedling vigor, is good for site stabilization in coarse soils. Blue wildrye *(Elymus glaucus)* is a native, cool-season bunchgrass commonly used in erosion control in forested sites where rapid slope or site stabilization is needed. Rocky Mountain beeplant *(Cleome serrulata)*, evening primrose *(Oenothera caespitosa and O. deltoides)*, 'Bandera' Rocky Mountain penstemon *(Penstemon strictus)*, showy penstemon *(Penstemon speciosus)*, and narrow-leafed phacelia *(Phacelia linearis)* are native forbs that perform well in disturbed areas, thereby helping to reduce erosion. Grass-like plants such as sedges, spikerushes *(Eleocharis* spp.*)*, rushes *(Juncus* spp.*)*, bulrushes *(Scirpus* spp.*)*, and cattails *(Typha latifolia)* are helpful for erosion control in riparian areas.

Establish species to minimize weed invasion or reestablishment

An effective seed mix that provides weed competition usually consists of aggressive, quick-establishing grasses and forbs. Competition-intolerant species should not be considered. Recent research suggests enhanced forb diversity may result in preferential resource use by desired species. For instance, spotted knapweed demonstrated strong performance in sites with low diversity, especially when native forbs were absent. This suggests that sites with a high native forb diversity might better compete with spotted knapweed. It is recommended that the native forb component of plant communities be maintained or restored to resist weeds and safeguard ecosystem stability. Once removed, forbs are difficult and expensive to reestablish.

For a plant community to be "weed-resistant," it should effectively and completely utilize all available resources. Design seed mixes, which include shallow- and deep-rooted forbs and grasses that grow early and late in the year, maximize nutrient and water use. Cool-season species use soil resources from the upper soil profile and begin seed production in early summer. Competitive, native, cool-season grasses include thickspike wheatgrass, slender wheatgrass, and Canada wildrye. Nonnative grasses that are highly competitive with weeds include several cultivars with long growing seasons and extensive root systems, including pubescent wheatgrass *(Elytrigia intermedia* ssp. *trichophorum)*, intermediate wheatgrass, hard fescue *(Festuca trachyphylla)*, and 'Bozoisky' Russian wildrye (photo 3). Solid or mature stands of meadow brome *(Bromus biebersteinii)* or sheep fescue, both nonnative bunchgrasses, have demonstrated some resistance to weed invasion.

Competitive native forbs suitable for revegetation include blue flax *(Linum lewisii)*, yarrow *(Achillea millefolium)*, Maximilian sunflower *(Helianthus maximiliani)*, common gaillardia *(Gaillardia aristata)*, and fireweed *(Chamerion angustifolium)*. Lacy phacelia is an aggressive native annual with good competitive abilities. Numerous other native forbs are available and suitable for revegetation efforts.

Deeply tap-rooted shrubs, such as sagebrush, rabbitbrush *(Ericameria* spp.*)*, bitterbrush, or fourwing saltbush, can utilize resources from the lower soil profile throughout the growing season. Shrubs can be included as seeds in a mix or planted as young plants. Furthermore, shrubs may increase establishment of understory species by . . .

- increasing water availability by intercepting water from light rains and snow,
- increasing infiltration rate and water-holding capacity by improving soil structure,
- enhancing soil fertility and seedbanks by concentrating nutrients and catching windblown soil, seeds, and mycorrhizal spores, and
- decreasing understory temperatures to reduce evapotranspiration and increase nutrient cycling.

Restore a healthy plant community

A healthy plant community is important to sustainable invasive weed management as well as meeting other land use objectives. Developing a healthy plant community involves steadily removing

Photo 3. Hard fescue is a long-lived, nonnative bunchgrass that may compete well with invasive species.

weeds and replacing them with desired plants. This replacement can occur naturally, when desired vegetation is adequate within the degraded site, or through revegetation. Species selection for restoring a desired or healthy plant community should be based on revegetation goals and objectives and specific conditions of the site.

Long-term maintenance that favors the seeded species will be necessary for the development of a healthy plant community. The desired grass component should be managed to encourage strong vigor and growth by avoiding heavy or untimely grazing practices. The forb component should be managed to encourage the highest levels of diversity, a condition that may be promoted by periodic prescribed burning, if appropriate.

Step 8—Determine Seeding or Planting Method

The most common seeding methods are drilling, broadcasting, and hydroseeding. Hay mulch seeding is less common. "Island" planting, plugging, and sprigging methods place whole plants or rhizomes into the soil. The seeding method depends on site accessibility and terrain, seedbed characteristics, species and seed characteristics, and economic constraints.

Drill seeding

A nonrocky site accessible to equipment should be seeded with a no-till drill. This is a tractor-pulled machine that opens a furrow in the soil, drops seeds in the furrow at a specified rate and depth, and rolls the furrow closed. This method enhances seedling establishment and seed depths. Also, seeding rates are controlled and seed-to-soil contact is high. Ideal seeding depths range from ¼ inch for small seeds to about ½ to 1 inch for large seeds. Seeding depth varies with site characteristics that influence soil moisture (photo 4). Chief among them are soil texture, site exposure, and aspect. Though drill seeding can enhance seedling establishment, there are some shortcomings, such as the following:

- The plants that germinate develop in rows resembling a crop rather than a native plant community. This can be avoided by seeding in two perpendicular passes.

- Long, narrow seeds are difficult to plant because they become bridged within the drill.

- Some species require shallow placement in the soil while others require deeper placement. Therefore, two separate seeding operations may be needed when planting a mix. Alternatively, more than

one seed box may be needed on the drill so that drop tubes can be pulled to broadcast smaller-seeded species.

- Seeds of various sizes will separate in the seed container. Small seeds vibrate to the bottom of the seed box and fall faster than larger seeds. Adding a carrier, such as cracked corn or rice hulls, vermiculite, or perlite, can mitigate the size or weight segregation of seeds. A carrier also controls the flow of problematic seeds with long awns.

- Drill furrows can cause soil erosion from water flow unless seeding is performed along slope contour.

Broadcast seeding

Broadcast seeding is a commonly used method on steep, rocky, or remote sites inaccessible to equipment. Small areas can be seeded with a hand spreader, whereas large commercial spreaders can seed substantial areas. Aircraft can seed inaccessible areas.

Seedbed preparation is recommended prior to broadcast seeding. On accessible sites, dragging small chains or harrowing can roughen and loosen the soil surface. Roughening creates safe sites, ensuring proper seed placement for establishment. Following seeding, roughen the soil surface again and, if possible, lightly roll or pack the soil. Adding hydromulch over broadcast seed can assist establishment.

Imprinting uses heavy, textured rollers to make imprints in the soil surface, thereby aiding water infiltration and soil aeration. The imprints work as small catch basins, enhancing water accumulation for improved seed germination. Imprinting can also be used in conjunction with broadcast seeding. Large seeds can be broadcast in front of the imprinter and pressed firmly into the soil. Small seeds are typically broadcast behind the imprinter so splash erosion covers seeds in the depressions without burying them too deeply. Imprinters fitted with seed bins can be stand-alone seeding devices.

If seedbed preparation is not possible, double or triple the broadcast seeding rate appropriate for drill or plowed-ground seeding. This will ensure that an adequate amount of seed find safe sites for germination. Also, consider short-term livestock trampling so hoof action can push the seeds into the soil.

Photo 4. Drill seeding controls seeding rates and promotes germination by placing seeds at specific depths.

Hydroseeding

Hydroseeding is a form of broadcast seeding in which the seeds are dispersed in a liquid under pressure. The hydroseeder consists of a water tanker with a special pump and agitation device to apply the seed and may include mulch or other additives. Sometimes germination and establishment results are less satisfactory than drill or broadcast seeding because the seed does not always make good seed-to-soil contact. However, hydroseeding onto a freshly roughened or disturbed site can provide adequate seed-to-soil contact. Hydroseeding is usually the only practicable method for seeding slopes 3:1 or steeper.

Hay mulch seeding

Hay mulch seeding involves spreading seed-containing hay over a prepared seedbed. Hay mulch seeding is useful because the hay is both the seeding method and mulch. However, because each species produces seed at slightly different times, some species can be absent from a hay harvest. Hay should be cut when the dominant species is at an optimal stage of maturity and spread within the hay during the best seeding. Spreading hay by hand is practicable on small sites, but chopper-shredders that shred and apply the hay are better for larger sites. To avoid loss to wind, hay can be crimped into the soil with machinery, pushed into the soil by livestock trampling, or held down upon the soil with an organic tackifier. Always make sure the hay is weed free.

Island planting

Planting nursery stock can complement reseeding and increase the chances of revegetation success with rapid plant establishment. Planting also circumvents the critical germination and establishment stages. Purchased stock can be costly. However, planting fewer individuals in “islands” where central, established stands of plants can reproduce and eventually spread may reduce costs. The results of such “islands” will be long term. An immediate increase in the number of nonseeded species resulting from this practice should not be anticipated. Areas can be “island seeded” by using a drill seeder to seed wide strips. Over time, the

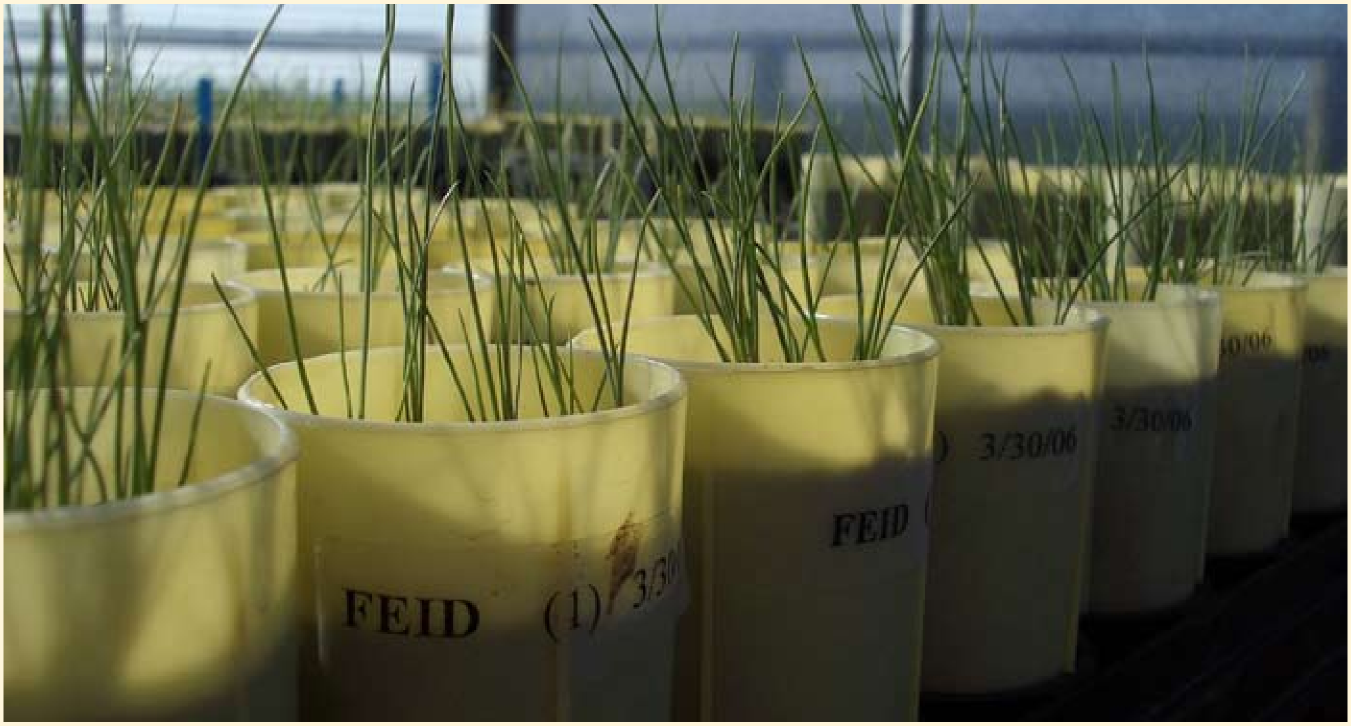


Photo 5. In riparian areas, greenhouse-grown plugs have a much higher establishment rate than straight seeding.

seeded strips spread into the unseeded areas. Careful monitoring of weeds in the unseeded areas until vegetation is established is important.

Plugging

Establishing wetland/riparian plants from seeds is difficult because site hydrology must be carefully controlled and precise amounts of heat, light, and water are needed. Broadcast seeding of wetland/riparian species is not used as a primary means of revegetation but as a method to increase overall species diversity. Experts note that planting plugs is preferred to broadcast seeding or collecting wildlings (plants collected from wild populations) (photo 5). Plugs should be planted on 18- to 24-inch centers, or about 11,000 plugs per acre. The plants will spread into the unplanted areas.

Plugs have been successfully planted from April through late October. Spring planting is generally preferred over fall planting because the plugs will have a longer establishment period. Fall planting may result in lower establishment because of the shorter growing season and damage from frost heaving.

Sprigging

Sprigging involves planting rhizomes at a depth of 3 to 4 inches. Specialized equipment for digging and planting sprigs is commercially available. Plants can be established by sprigging at slightly higher salinity levels than by seeding because the rhizomes are more salt tolerant than seedlings and can be placed below the highest concentration of salts in the soil profile. Rhizomatous grasses will continue to spread once established. The lack of an available sprig source and equipment are the main limitations to this method.

Step 9—Calculate Seeding Rate

Depending on the species, seeding rates are usually 20 to 50 viable seeds per square foot. The actual rates vary depending on many factors, including weed interference, differences in seedling vigor, site conditions, and the components of a seed mix. When a species is used as a component of a mix, adjust to the percentage of mix desired. (See example below.) When a species is desired as a pure stand, use the recommended amount of pure live seed (PLS) found in tables 1–3. Consider increasing rates 30 percent for nonirrigated sites, doubling rates when seeding a severely burned area (80 seeds per square foot for perennial grasses), and doubling or tripling rates if broadcast seeding or hydroseeding. Increasing seeding rates adds expense to a project but may ensure establishment and increase the chances of long-term revegetation success.

Pure live seed is a measure describing the percentage of a quantity of seed that will germinate. PLS equals the percent of purity multiplied by the percent of germination (figure 7). Multiply the purity percentage by the percentage of total viable seed (germination plus dormant), then divide by 100 to calculate the PLS content of a given seed lot. Because the PLS measurement factors in quality, purchasers can compare the quality and value of different seed lots. Consider this example (table 5):

Seed lot A may appear to be the better value because its cost is only $1.75 per bulk pound, whereas the cost for seed lot B is $2.00 per bulk pound. However, the PLS content of seed lot A is inferior to seed lot B. To properly compare the value, a purchaser would calculate the cost per PLS pound by dividing the bulk cost by the percent PLS (PLS cost = bulk cost × 100 / percent PLS). The calculation shows seed lot B is the better value at $2.44 per PLS pound; seed lot A costs $3.18 per PLS pound. Precise ordering of seed based on PLS helps purchasers to get full value for the money they spend on seed.

When designing a seed mix, the percent of each species desired in the mixture needs to be determined. Multiply the percent desired in the seed mix times the pounds of PLS recommended per acre to get the PLS mix per acre.

Figure 7. Determining Bulk Rate for Drill-Seeding

When seeding the recommended PLS seeding rate using a drill, the bulk rate of seeding needs to be determined since the material in the seed lot cannot be removed. To calculate pounds of bulk seeding per acre, divide pounds of PLS at the recommended rate per acre by the percent PLS.

For example, if the recommended seeding rate for Hycrest crested wheatgrass is 10 pounds PLS per acre and the PLS is calculated to be 80 percent, the bulk rate needed to seed the recommended PLS is determined thus:

10 PLS/**0.080** PLS = **12.5 lbs.** *bulk seeding rate per acre*

Figure 8. Conditions for Successful Establishment

Successful establishment may require all of the following conditions:

Seed placement in favorable microsites

Precipitation adequate to stimulate germination

Recurrent precipitation for seedling establishment

Low levels of herbivory

Absence of competition during establishment

Also, when designing a seed mix, calculate the number of pounds for each species separately and then divide by the number of species in the mixture. Then take the pounds per acre and multiply by the total acres to be seeded. For example, for a mix of 4 grasses to be seeded on 10 acres, divide the pounds per acre for each species by 4 and then multiply by 10. Seeding rates for timothy are 8 to 10 pounds PLS per acre when seeded alone and 4 to 5 pounds PLS per acre when seeded with another species, usually a legume. (For slender wheatgrass: 12 lb per acre / 4 species × 10 acres = 30 lb) given:

Of the desired seed mix, 85 percent will be bluebunch wheatgrass. This lot of seed has a 90-percent PLS. The recommended seeding rate is 12 pounds PLS per acre. The remaining 15 percent of the mix will be small burnet. This lot of seed has an 85-percent PLS. The recommended seeding rate is 20 pounds PLS per acre. Thus —

(Bluebunch 85%) × (12 lb PLS / acre) = 10.2 lb PLS / acre mixed
(Small burnet 15%) × (20 lb PLS / acre) = 3.0 lb PLS / acre mixed
determine:
Amount of bulk seed (mixed) per acre using the formula above

solution:
Bluebunch: 10.2 lb PLS / 90% PLS = 11.3 lb bulk mixed / acre
Small burnet: 3.0 lb PLS / 85% PLS = 3.5 lb bulk mixed / acre

Step 10—Planting Mature Plants

Planting mature plants circumvents germination and establishment (figure 8). Planting can complement reseeding and increase the chances of revegetation success by providing rapid plant establishment. Local ecotypes can be obtained as salvaged, locally collected, or containerized plants propagated by seeds (photo 6). Sometimes planting is the only feasible method of establishing certain plants. Seeds of many shrubs, for instance, may germinate occasionally, establish poorly, or grow slowly under natural conditions.

Though sometimes difficult to attain, successful transplantation of salvaged or locally collected native plants may preserve local native gene pools and ecotypes. Propagation by seeds in containers, however, can attain the same purpose and has demonstrated better success. Planting bareroot stock can also be considered, but may demonstrate lower survival rates compared with container-grown plants.

To increase planting success and reduce weed interference, plant during late winter or early spring. Planting during dormant periods helps plants withstand planting rigors and increases the chances that adequate moisture will be available during the onset of active growth. If planting during the growing period, water at the time of transplanting and consider occasional, but temporary, short-term watering. Also, consider adding finished compost during planting to reduce transplant shock and increase plant survival, especially on low fertility, dry, or sandy soils.

Photo 6. Salvaging and transplanting native plants can complement revegetation and promote native plant conservation.

Some plants tolerate transplanting better than others. Rough fescue *(Festuca scabrella)*, a native bunchgrass, can usually tolerate it. Native plants growing in disturbed areas have been found to be well suited for transplanting also. They may include Rocky Mountain beeplant, fireweed, and common and pale evening primrose. Plants with taproots and extensive root systems are least likely to tolerate transplanting.

Planting fewer individuals in islands where a central, established stand of plants can reproduce and spread throughout the area can reduce time, effort, and costs of planting. Island planting containerized shrubs can complement a revegetated site and increase establishment of understory species.

Planting greenhouse-grown plugs in wetland/riparian areas have a much higher establishment rate than straight seeding and they spread faster and farther than transplanting wildlings or plants collected from wild populations. However, transplanting wetland plants, which may be done successfully because of their sturdy root systems, may be considered a useful revegetation method in some cases. Consider transplanting wildlings when the plants are easy to propagate by adventitious roots or sod when they are small. Make sure the wildlings are placed in a wet, low-water-stress environment. When removing wetland plants, dig no more than 14 inches of plant material from a 4-foot, 2-inch area and do not dig deeper than 5 or 6 inches. Leave the soil on the removed plants to ensure the mycorrhizae remain intact.

Step 11—Determine the Best Time to Revegetate

Money and effort spent on revegetation will be wasted unless management practices favor the seeded species.

The right time to seed depends on the soil texture and the species being seeded. Warm-season species are commonly seeded during late spring or early summer. Warm-season plants initiate growth in early summer. Fall-dormant seedings are common with cool-season species or when mixtures of grass, legumes, forbs, and shrubs are used.

Dormant seedings should occur after the soil temperature has fallen below 50 °F for 1 to 2 weeks. This period is usually during late fall (that is, late October and early November), just before the soil freezes and when temperatures and moisture remain low enough to prevent germination. Dormant

Photo 7. Indian ricegrass is a native bunchgrass that requires cold stratification to break dormancy. This can be provided with a fall-dormant seeding.

seedings are important for many cool-season species that require cold stratification. For example, Indian ricegrass (photo 7) needs at least 30 days of exposure to cold soil to meet its stratification requirements. When conditions are not adequate for a fall-dormant seeding, early-spring seedings may appear because of late snows and early rains. Plant tree and shrub seedlings during early-spring dormancy. Plant greenhouse-grown plugs in wetland/riparian areas in June, when warm temperatures, long days, and adequate water prevail. Seeding directly into the ash layer immediately after a fire is the best time to seed burned areas.

Soil texture can influence the timing of seeding. When seeding cool-season species on heavy- to medium-textured soils, consider a very early-spring seeding. On medium- to light-textured soils, consider a late-fall seeding. Generally, a late-fall-dormant seeding is best for cool-season species regardless of soil texture.

Late-summer planting—prior to mid-August—of cool-season species should only be done if supplemental water is available from irrigation or as stored soil moisture. With irrigation, planting can occur from spring until mid-August.

Step 12—Assist Establishment

Seedling establishment is the most critical phase of revegetation. Many factors can influence establishment, including variations in soil properties, site exposure, and climate. Seedlings usually fail to establish from a combination of factors. The most predominant factors are insufficient soil moisture and intense weed competition.

Enhance establishment and seedling survival with the following methods, when appropriate:

- Use species adapted to local site conditions.
- Use high-quality, certified seed.
- Reduce weed competition through management, “single-entry” revegetation, or nutrient reduction with cover crops when planting native species with low nutrient requirements, such as bluebunch wheatgrass.
- Inoculate legume seeds with proper bacteria to ensure maximum nitrogen fixation in sites lacking a healthy nitrogen cycle. This will improve nutrient uptake, water transport, drought tolerance, and resistance to pathogens.
- Place seeds in contact with soil using a drill seeder or prepare a seedbed before broadcast seeding and lightly pack the soil. Also, consider applying hydromulch following broadcast seeding.
- Increase seeding rate to improve the chances for an adequate amount of seeds finding safe sites if the site is not accessible to equipment. Increasing seeding rates may also improve desired species competition with invasive weeds.
- Plant plugs to establish wetland/riparian plants.
- Avoid covering wetland/riparian seeds with soil, because heat and light are needed for proper germination.
- Use a land imprinter to form depressions in the soil. These depressions retain moisture at the surface longer than smooth soil surfaces. Soil depressions create good conditions for soil coverage of broadcasted seeds as the sides of the depression slough off and trap windblown particles.
- Add small amounts of water to temporarily encourage establishment, but only in cases when natural precipitation has proved inadequate. (An initial watering is recommended after transplanting dur-

ing the growing season.) Supplemental watering may stimulate germination but will have little lasting, long-term effect. Frequent watering may result in poor plant adaptation and only short-term success once supplemental water is withdrawn. Consider using commercial water-holding polymers during establishment to provide young plants with moisture.

- Defer grazing by fencing or herding until vegetation has become well established, usually after two growing seasons. If palatable, slow-maturing shrubs are recovering; do not graze until the shrubs produce viable seeds.

Treating seeds can also enhance establishment. Consider using the following treatments, when appropriate:

- Seed priming starts germination, allows it to progress to a certain point, and then suspends it. The primed seeds can continue germination in the field when conditions are favorable. Seed priming is helpful with revegetation of weed-infested sites because the first seedlings to capture available resources have a competitive advantage.

- Seed fungicide protects seeds from numerous soilborne organisms that can reduce germination and seedling survival when soil moisture and surface relative humidity increase following rainfall. Consider this treatment in wet environments, especially with slow-germinating forbs.

- Seed stratification "fools" seeds into germinating by mimicking environmental conditions. Many upland species, such as beardless wildrye and Indian ricegrass, need cold stratification to break dormancy and germinate. There are many types and breaking strategies of dormancy.

- Seed scarification breaks the seed coat with acid or by mechanical means. Seeds with considerable dormancy can benefit from this treatment.

- Seed coating involves applying a layer of material around the seed. This material may contain fertilizers, growth regulators, pesticides, or mycorrhizal fungi.

Mulching

A mulch cover protects soil and seeds from erosion by wind and water, conserves soil moisture, and moderates soil temperatures to improve the chances of germination and establishment success.

Hay mulch—Native, certified weed-free hay is a beneficial mulch because it contains a small amount of nitrogen from leaves, flowers, and seed heads. Native hay may also contain seeds of native plants, whereby volunteer stands may develop and produce communities that are more diverse. Native hay harvests typically include needle-and-thread grass, western wheatgrass, and bluebunch wheatgrass. When attempting to sow needle-and-thread grass, the long awns can prove problematic. They can become useful appendages in hay mulches by working the seeds into the ground, improving germination. Mulches are used for short-term protection on moderate to flat slopes. Use enough hay to cover the soil completely. Pliable mulch can be crimped into the soil or trampled by livestock to prevent losing it to the wind. Another option is to use an organic tackifier, which is glue that breaks down into natural byproducts.

Stubble mulch crops—Sterile forage sorghums or millets are planted in the growing season prior to the desired species seeding. After crop maturation, native seeds are sown into the residual standing dead material. Standing stubble improves soil moisture during germination by trapping snow.

Companion crops—Fast-growing, nonpersisting annuals or short-lived native perennials are seeded with perennial grasses to protect soil and the young, slower establishing perennial-seeded grasses. Sterile hybrids, such as Regreen and Triticale, were developed specifically for use as cover or companion crops. They establish rapidly, do not persist or reseed into successive years, and are completely outcompeted by the seeded species. Triticale is often used as a companion crop when maximum forage is desired while slower-developing perennials establish. Avoid using cereal rye as a companion crop as it is very competitive and may spread to surrounding sites.

Hydromulch—Hydraulic mulch is comprised of virgin wood fibers or recycled paper mixed into a water slurry and sprayed onto the ground. Long wood fibers intertwine with one another to form a rigid bond. Applying a tackifier with hydromulch provides excellent erosion protection. Recycled paper mulch decomposes quickly and provides good protection on relatively flat slopes. It is particularly useful with quick-establishing vegetation or following broadcast seeding.

Bonded fiber matrix—This matrix is a sprayed-on mat consisting of a continuous layer of elongated fiber strands held together by a water-resistant bonding agent. A continuous cover is needed to create the integrated shell. Hire a certified contractor to apply the material appropriately because if it is applied too thickly, it can prevent penetration by seedling shoots.

Erosion control blankets—These blankets are usually composed of woven organic material such as straw or coconut fiber. They are also designed to allow seed germination and to permit stems to grow through and above the mat. Increase seeding rates if light-dependent species are being sown under blankets or mulch. As the fabric ages it becomes incorporated into the soil and decomposes. Mats are expensive but very effective. For steep slopes (3:1 and greater) that require long-term protection, mats are sometimes the only viable option.

Step 13—Monitor

Proper site monitoring identifies problems that can prevent or interfere with a successful revegetation project. Monitoring is a cost-effective component that can identify early problems such as the following:

- unexpected changes that shift species composition or abundance,
- invasion or reestablishment of weeds from an existing seedbank,
- preferential foraging by livestock or wildlife,
- erosion that damages plant materials and the base,
- small areas of revegetation failure, and
- unfavorable moisture.

Site monitoring can identify and rectify these problems in time to allow successful revegetation, such as:

- Reducing weed interference before, during, and after seeded species establishment. The first year or two of a project may be dedicated entirely to weed removal if the site is moderately to heavily infested with invasive weeds.
- Providing temporary water until seedlings are established when adequate precipitation is lacking. Then, if the species is properly matched to site conditions, the plants should continue to develop on their own.
- Erecting protective fencing to mitigate selective grazing by wildlife and livestock.
- Using mulch to protect seeds, prevent soil erosion, and conserve soil moisture.

Site monitoring can range from quick visual inspection to an in-depth study of species composition, distribution, and density. Monitoring frequency will depend on project goals and site conditions. A site prone to low moisture, high wind erosion, or weed invasion should be monitored frequently.

Significant results of a seeding project may take 3 to 5 years because perennial grass and forb seed often lie dormant in the soil until climate conditions are appropriate for germination.

Step 14—Long-Term Management

To maintain the desired plant community, long-term revegetation success requires continuous monitoring and evaluation for timely adjustments. Money and effort spent on revegetation will be wasted unless management practices favor the seeded species. Long-term maintenance includes frequently monitoring the site and adjacent areas to detect and eradicate new weeds early. Long-term maintenance also avoids heavy grazing to promote seed to set and disperse. This will perpetuate and maintain stands.

Encourage seeded species growth and vigor to extend the productive life and economic returns of seeded pastures. Resources for invasive weed establishment and growth are limited. A grazing management plan should be designed to encourage desired species. For instance, Indian ricegrass is highly palatable and nutritious and is regarded as very valuable winter forage. However, heavy grazing has resulted in its virtual elimination from many rangeland systems.

The following strategies benefit desired plants and enhance and promote healthy rangeland systems:

- Fence seeded pastures separately from native rangeland. Also, fence seedings of different species or mixtures based on differences in maturity, palatability, and grazing tolerance among species. For instance, Russian wildrye has excellent year-round palatability and nutrition and should be fenced to guard against overuse.
- Equalize grazing pressure among rangeland plants with multispecies grazing. Domestic sheep assist in the successional process towards a perennial grass community by avoiding grasses and instead, applying grazing pressure on native forbs and nonnative weeds. On moderately stocked rangelands, one ewe per cow/calf pair can be added without reducing cattle production.
- Defer grazing until seeded species have become well established, usually after two growing seasons.
- Avoid heavy grazing by using proper stocking rates and grass utilization levels. Heavy grazing stops grass growth and reduces vigor by affecting carbon fixation. Even aggressive-growing, nonnative grasses cannot tolerate close and continuous grazing. Such grazing also puts the grazed plant at a disadvantage in competing for resources with an ungrazed weed. The establishment of diffuse knapweed *(Centaurea diffusa)* was enhanced only when defoliation of the native bluebunch wheatgrass exceeded 60 percent. This suggests that defoliation beyond this level reduced grass competitiveness.
- Avoid grazing the same plants at the same time every year by altering the season of pasture use. Outline the movement of livestock across pastures throughout the year.
- Avoid close grazing during fall green-up. This practice is damaging to all grass species. Also, avoid grazing cool-season grasses from early August (30 to 45 days prior to the average first frost) to the first "killing" frost (a frost with several successive days of temperatures around 25 °F)

in mid-October. This period of rest allows roots to replenish reserves for winter survival and early-spring growth.

- Rotate livestock use among pastures to allow plant recovery before regrazing the pastures. Recovery time depends on the species, weather, and soil fertility. Plants with abundant leaves that remain after grazing will recover more quickly than closely grazed plants. A minimum recovery period of 21 to 30 days is usually needed when growing conditions are optimal in spring. Recovery periods of 2 to 3 months may be required after grazing in summer or early fall.

- Prevent weed seeds from reaching the soil surface by minimizing bare ground with plant litter accumulation.

Regular range monitoring should be performed to evaluate the efficacy of the grazing program in maintaining the desired plant community. Range monitoring includes detecting changes in desired plant cover and noting such surface conditions as litter accumulation and exposed soil. Annual evaluations are essential to perform needed adjustments in a timely manner. Evaluate management practices annually, and modify when necessary.

Conclusion

Revegetation is helpful and often necessary for speeding up natural recovery and mitigating or preventing soil erosion and invasive weed establishment and growth. However, revegetation necessity should be based on the abundance of desired plants and propagules at the site. Revegetation is also helpful in cases where rangeland improvement is desired.

Numerous steps should be considered and implemented to increase the likelihood of a successful revegetation project. Often, these steps include planned events, such as topsoil and vegetation salvage and replacement operations, or implementation of significant weed management plans to reduce weed interference on seeded species. Weed management plans should also encourage the preservation of native forbs for ecosystem stability and sustainable weed management. Successful revegetation also includes determining appropriate species based on revegetation goals, environmental conditions, and site characteristics as well as utilizing the most appropriate seeding method at the proper time. Soil amendments, seed treatments, and mulching are used to assist seeded species establishment. Monitoring the revegetated site is necessary to quickly identify problems and correct them. Long-term management of the site should favor the seeded species.

Table 1. Native grasses and grass-like plants recommended for Great Basin revegetation projects

Name	Cultivars	Preferred Soil Type	Minimum Ppt.* (in.)	Erosion Control	Pure Stand PLS† rate / acre (lb.)	Notes
Bunchgrasses—Short to Medium						
Indian Ricegrass (*Achnatherum hymenoides*)	Nezpar Paloma Rimrock	Sand to sandy	8	Good	12	Drought tolerant; easy to moderate establishment; relatively short-lived; useful in coarse soils on low-fertility sites; highly palatable and nutritious.
Squirreltail (*Elymus elmoides*)	Sand Hollow Toe Jam Creek	Sandy to loamy	6	Good	12	Short-lived; fair seedling vigor; becomes palatable at maturity; often seeded as a midsuccessional species; competitive cheatgrass and medusahead.
Idaho Fescue (*Festuca idahoensis*)	Joseph Nezpurs	Silty-loamy to clayey	10	Good	8	Moderately drought tolerant; slow establishment; poor seedling vigor; good palatability.
Sandberg's Bluegrass (*Poa Plains sandbegii*)	High	Sandy to clayey	8	Poor	4	Very drought tolerant; slow establishment; can withstand considerable grazing pressure.

Table 1. Native grasses and grass-like plants recommended for Great Basin revegetation projects—continued

Name	Cultivars	Preferred Soil Type	Minimum Ppt.* (in.)	Erosion Control	Pure Stand PLS† rate / acre (lb.)	Notes
Bunchgrasses—Medium to Tall						
Mountain Brome (*Bromus marginatus*)	Bromar Garnet	Silty-loamy to clayey	16	Very Good	12	Rapid establishment; short-lived; adapted to relatively moist soils; good livestock forage value.
Tufted Hairgrass (*Deschmsia caespitosa*)	Nortran Peru Creek	Silty-loamy to clayey	20 (Riparian)	Good	2	Long-lived; most common in moist sites and at higher elevations; very palatable to livestock and wildlife.
Snake River Wheatgrass (*Elymus wawawaiensis*)	Secar	Sandy loam to silty loamy	8	Good	12	Very drought tolerant; slow to establish; well adapted to sites with long, hot summer; somewhat competitive with annual weeds; establishes well when seeded in mixes with other natives.
Prairie Junegrass (*Koeleria cristata*)		Sandy	12	Good	2	Drought tolerant; easy establish-ment; good quality early spring forage.
Bluebunch Wheatgrass (*Pseudoroegneria spicata*)	Goldar Anatone P7	Silty-loamy to clayey	9	Good	12	Drought tolerant; moderate establishment; adapted to most sites, including nonproductive sites.

Table 1. Native grasses and grass-like plants recommended for Great Basin revegetation projects—continued

Name	Cultivars	Preferred Soil Type	Minimum Ppt.* (in.)	Erosion Control	Pure Stand PLS† rate / acre (lb.)	Notes
Sand Dropseed (*Sporobulus cryptandrus*)		Sandy	9	Good	2	Extremely drought tolerant; moderate palatability; prolific seed producer, tends to increase on poor condition rangelands; seed should be scarcified before planting.
Columbia Needlegrass (*Stipa thurberiana*)		Silty-loamy to clayey	12	Good	8	Slow establishment, but survival can be high; tolerant of harsh environments; occurs at higher elevations; good palatability.
Needle-and-Thread (*Stipa comata*)		Sandy to silty-loamy	10	Good	14	Drought tolerant; long-lived; useful for disturbed sites and winter forage.
Thurber's Needlegrass (*Stipa thurberiana*)		Loamey to clayey	9	Good	10	Slow establishment; seedlings are poor competitors; palatable livestock and wildlife.
Bunchgrass—Tall to Very Tall						
Great Basin Wildrye (*Elymus cinerus*)	Magnar Trailhead	Silty-loamy to clayey	8	Very Good	11	Establishment requires 2 to 3 years; not very competitive; adapted to a wide variety of sites in winter-wet and summer-dry areas; excellent winter forage and cover.

Table 1. Native grasses and grass-like plants recommended for Great Basin revegetation projects—continued

Name	Cultivars	Preferred Soil Type	Minimum Ppt.* (in.)	Erosion Control	Pure Stand PLS† rate / acre (lb.)	Notes
Blue Wildrye (*Elymus glaucus*)	Elkton Arlington	Sandy to silty-loamy	12	Excellent	10	Rapid establishment; short-lived, but stands ready to reseed themselves; common on moist sites, but moderately drought tolerant.
Slender Wheatgass (*Elymus trachycaulus*)	Primar Pryor Revenue San Luis	Sandy to clayey	16 (Riparian)	Very Good	12	Moderate drought tolerance; rapid establishment; short-lived; saline-tolerant; useful where quick native, nonaggressive perennial cover is desired.
Big Bluegrass (*Poa ampla*)	Sherman	Silty-loamy to clayey	8	Good	5	Easy establishment; intolerant of poorly drained soils or high water tables; excellent palatability; stays green longer than other species.
Rhizomatous Grasses						
Streambank Wheatgrass (*Elymus lanceolatuse*)	Sodar	Sandy to clayey	8	Excellent	12	Drought tolerant; moderate establishment; short-lived; especially well suited for stabilizing silty to sandy soils on upland sites.

Table 1. Native grasses and grass-like plants recommended for Great Basin revegetation projects—continued

Name	Cultivars	Preferred Soil Type	Minimum Ppt.* (in.)	Erosion Control	Pure Stand PLS† rate / acre (lb.)	Notes
Thickspike Wheatgrass (*Elymus macrourus*)	Bannock Critana Schwendimar	Sandy to clayey	8	Excellent	10	Drought tolerant; easy to fair establishment; long-lived; good year-round palatability.
Creeping Red Fescue (*Festuca rubra*)	Fortress Illahee	Sandy to acidic	18	Excellent	3	Drought resistant after establishment; hardy, wear-resistant, and shade tolerant; requires good moisture to establish.
Beardless Wildrye (*Leymus triticoides*)	Shoshone	Sandy	10	Very Good	20	Moderately drought tolerant; difficult establishment; saline tolerant.
Western Wheatgrass (*Pacopyrum smithii*)	Rosana Rodan Arriba	Silty-loamy to clayey	10	Moderate	16	Drought tolerant; fairly easy to moderate establishment; long-lived.

* Ppt. = precipitation.
† PLS = pure live seed.

Table 2. Nonnative species recommended for Great Basin revegetation projects

Name	Cultivar	Preferred Soil Type	Minimum Ppt.* (in.)	Erosion Control	Pure Stand PLS† rate / acre (lb.)	Notes
Annuals						
Italian Ryegrass Gulf (*Lolium perenne* ssp. *multiflorum*)		Silty-loamy	10	Very Good	16 to 35	Quick and easy establishment; highly palatable to livestock and wildlife.
Triticale (wheat x cereal a rye) (*Triticum aestivum* x *Secale cereale*)	Spring and winter varieties	Silty-loamy to clayey	12	Very Good	60 to 100	Quick and easy establishment; good forage production and highly palatable; often used when maximum forage is desired while slower perennials establish.
Regreen (wheat x tall wheatgrass) (*Triticum aestivum* x *Thinopyrum ponticum*)		Silty-loamy	12	Excellent	20 to 40	Annual or short-lived perennial sterile hyrid cross; used as a soil stabilizer and cover crop; quick and easy establishment; does not persist; drought tolerant.

Table 2. Nonnative species recommended for Great Basin revegetation projects—continued

Name	Cultivar	Preferred Soil Type	Minimum Ppt.* (in.)	Erosion Control	Pure Stand PLS† rate / acre (lb.)	Notes
Bunchgrasses—Short to Medium						
Hard Fescue (*Festuca longifolia*)	Durar Serra Crystal Aurora	Sandy to clayey	16	Very Good	10	Moderately drought tolerant; slow but persistent establishment, long-lived; well suited for low fertility, upland or hilly sites; used for low-maintenance cover; poor palatability and nutrition.
Sheep Fescue (*Festuca ovina*)	Covar Bighorn	Sandy to clayey	10 to 12	Very Good	10	Dought tolerant; slow establishment but tenacious; competitive once established; poor palatability to livestock but used by wildlife.
Bunchgrasses—Medium to Tall						
Crested Wheatgrass (*Agropyron crisatum*)	Fairway Ephraim Douglas Roadcrest	Silty-loamy to clayey	10	Good	6	Excellent seedling vigor; fairly easy to establish; drought tolerant.
Standard Crested Wheatgrass (*Agropyron desertorum*)	Nordan Hycrest	Sandy to clayey	10	Good	6	Easy to establish; very drought tolerant; very similar to crested wheatgrass but more drought tolerant and productive.

Table 2. Nonnative species recommended for Great Basin revegetation projects—continued

Name	Cultivar	Preferred Soil Type	Minimum Ppt.* (in.)	Erosion Control	Pure Stand PLS† rate / acre (lb.)	Notes
Perennial Ryegrass (*Lolium perenne*)	Tetraploid	Silty-loamy to clayey	12	Very Good	15 to 35	Rapid establishment, short-lived; useful for pasture and range improvement; excellent palatability.
Timothy (*Phleum pretense*)	Climax Clair	Silty-loamy to clayey	16	Good	9	Easy establishment; adapted to moderately moist sites; commonly planted as pasture or hay grass and for seeding riparian areas; excellent palatability.
Bunchgrasses—Tall to Very Tall						
Altai Wildrye (*Leymus angustus*)	Prairieland Eejay Pearl	Silty-loamy to clayey	18	Very Good	15	Slow establishment; extremely saline- and alkaline-resistant.
Tall Fescue (*Lolium arundinaceum*)	Alta Fawn Kenmont Goar	All soils, except sandy	18	Good	8	Slow establishment, long-lived; tolerates wet, poorly drained sites; not recommended for native meadows or adjacent to wetlands because may be invasive.

Table 2. Nonnative species recommended for Great Basin revegetation projects—continued

Name	Cultivar	Preferred Soil Type	Minimum Ppt.* (in.)	Erosion Control	Pure Stand PLS† rate / acre (lb.)	Notes
Russian Wildrye (*Psathyrostachys juncea*)	Bozoisky Swift Mankota Vinall	Silty-loamy to clayey	12	Poor	7 to 10	Difficult establishment, long-lived; drought tolerant; useful for somewhat saline sites; excellent year-round palatability and nutrition.
Tall Wheatgrass (*Thinopyrum ponticum*)	Alkar Jose Orbit	Silty-loamy to clayey	12	Good	10 to 17	Easy establishment; suitable for most saline sites and some subirrigated cases; drought tolerant; low palatability.
Rhizomatous Grasses						
Meadow Foxtail (*Alopecurus pratensis*)	Silty-loamy to clayey		25 (Riparian)	Good	4 to 5	Slow establishment, long-lived; useful for pasture and range improvement; excellent palatability.
Meadow Brome (*Bromus biebersteinii*)	Regar Fleet Paddock McBeth Montana	Silty-loamy to clayey	16 (or Irrigated)	Good	12 to 17	Easy establishment, long-lived; very productive; highly palatable; drought tolerant; good winter hardiness.

Table 2. Nonnative species recommended for Great Basin revegetation projects—continued

Name	Cultivar	Preferred Soil Type	Minimum Ppt.* (in.)	Erosion Control	Pure Stand PLS† rate / acre (lb.)	Notes
Orchardgrass (*Dactylis glomerata*)	Many to clayey	Silty-loamy	16 (or Irrigated)	Good	8	Easy establishment, medium-lived; highly productive and palatable.
Newhy Hybrid Wheatgrass (*Elymus hoffmanii*)	Newhy to clayey	Silty-loamy	10	Good	14	Easy establishment; adapted to moist soils including moderately saline sites.
Pubescent Wheatgrass (*Elytrigia intermedia* spp. *trichophorum*)	Luna Manska Topar Greenleaf	Sandy to clayey	12	Very Good	12 to 14	Easy establishment, long-lived; moderately drought tolerant; not winter hardy; use limited to less harsh sites.
Intermediate Wheatgrass (*Thinopyrum intermedium*)	Amur Greenar Oahe Tegmar Rush	Silty-loamy to clayey	14	Excellent	10 to 12	Easy establishment, medium-to-long-lived; moderately drought tolerant; sites should not be subject to prolonged drought or several combinations of extreme cold and lack of snow cover.

* Ppt. = precipitation.
† PLS = pure live seed.

Table 3. Selected forbs and shrubs for Great Basin revegetation projects

Name	Cultivar	Preferred Soil Type	Minimum Ppt.* (in.)	Pure Stand PLS† rate / acre (lb.)	Notes
Native Forbs					
White Yarrow (*Achillea millefolium*)		Sand to sandy	10	1	Drought tolerant; aggressive.
Arrowleaf Balsamroot (*Balsamorhiza sagittata*)		Silty-loamy	12	7 to 15	Drought tolerant.
Rocky Mountain beeplant (*Cleome serrulata*)		Silty-loamy to clayey	16	10 to 16	Recommended for short-term stabilization in disturbed areas; attracts butterflies and bees.
Sulfur-Flower (*Eriognum umbellatum*)		Sandy to silty-loamy	10	4 to 7	Drought tolerant; requires well-drained soils; common on dry rocky slopes.
Blanketflower (*Gaillardia aristata*)		Sandy to silty-loamy	10	6 to 10	Fairly drought tolerant and suitable in mixtures for erosion control.
Blue Flax (*Linum lewisii*)	Appar	Sandy to silty-loamy	10	5	Drought tolerant; easy establishment; short-lived, but will reseed itself.

Table 3. Selected forbs and shrubs for Great Basin revegetation projects—continued

Name	Cultivar	Preferred Soil Type	Minimum Ppt.* (in.)	Pure Stand PLS† rate / acre (lb.)	Notes
Firecracker Penstemon (*Penstemon eatonii*)		Sandy to clayey	10	1 to 3	Known for its winter hardiness, seed production, and wide adaptability.
Palmer Penstemon (*Penstemon palmerii*)		Sandy to clayey	10	2 to 3	Does well on exposed and disturbed sites with well-drained sandy, gravelly soil; drought and cold tolerant.
Rocky Mountain Penstemon (*Penstemon strictus*)	Bandera	Sandy to silty-loamy	14	3 to 4	Widely adaptable; ability to persist on rocky or sandy loam sites; not recommended in areas with Lemhi penstemon, a sensitive plant, due to hybridization.
Scarlet Globemallow (*Sphaeralcea coccinea*)		Sandy	8	2 to 4	Tolerates disturbances, such as fire; hard seed coat often prevents germination.
Largehead Clover (*Trifolium macrocephalum*)		Sandy to loamy	14	6 to 8	Legume; fairly drought tolerant; high palatability.

Table 3. Selected forbs and shrubs for Great Basin revegetation projects—continued

Name	Cultivar	Preferred Soil Type	Minimum Ppt.* (in.)	Pure Stand PLS† rate / acre (lb.)	Notes
Introduced Forbs					
Cicer Milkvetch (*Astragalus cicer*)	Lutana Monarch Oxley	Silty-loamy	18	20 to 25	Legume; fair drought tolerance; slow establishment; long-lived; cold hardy.
Forage Kochia (*Kochia prostrate*)	Immigrant	Wide range	6	1 to 2	Very drought tolerant; competes well with invasive annuals.
Birdsfoot Trefoil (*Lotus corniculatus*)	Empire Viking	Silty-loamy to clayey	15	6	Legume; slow establishment; long-lived; grows best along and not in mixes.
Alfalfa (*Medicago sativa*)	Many	Silty-loamy	12	15	Legume; fair drought tolerance; easy establishment.
Sainfoin (*Onobrychis viciifolia*)	Eski Remont	Silty-loamy	12	35 to 45	Legume; drought tolerant; easy establishment; short-lived; alkaline tolerant.
Small Burnet (*Sanquisorba minor*)	Delar	Silty-loamy	10	20 to 24	Easy establishment; long-lived; valuable forage for wildlife.

Table 3. Selected forbs and shrubs for Great Basin revegetation projects—continued

Name	Cultivar	Preferred Soil Type	Minimum Ppt.* (in.)	Pure Stand PLS† rate / acre (lb.)	Notes
Alsike Clover (*Trifolium hybridium*)		Clayey	32	8	Legume; moderate ease of establishment; short-lived; tolerates alkalinity more than other clovers.
Native Shrubs					
Sagebrush (*Artemisia* spp.)		Sandy to clayey	8 to 12	Varies	Drought tolerant; many species and growth forms; request seed harvested in similar environmental conditions; important for forage and cover.
Fourwing Saltbrush (*Atriplex canescens*)	Wytana	Silty-loamy to clayey	8	13	Drought tolerant; relatively easy to establish; long-lived; salt tolerant.
Shadescale (*Atriplex confertifolia*)		Silty-loamy to clayey	4	Varies	Medium- to short-lived; often found in salty basins; may be difficult to establish due to seed dormancy.
Curl-Leaf Mountain Mahogany (*Cercocarpus ledifolius*)		Silty-loamy	11	Varies	Adapted to dry, shallow- to medium-deep soils on slopes and ridges from 2,000 to 9,000 ft. elevation; important winter browse plant.

Table 3. Selected forbs and shrubs for Great Basin revegetation projects—continued

Name	Cultivar	Preferred Soil Type	Minimum Ppt.* (in.)	Pure Stand PLS† rate / acre (lb.)	Notes
Rabbitbrush (*Chrysothamnus* spp.)		Sandy to clayey	8	Varies	Easy establishment.
Bitterbrush (*Purshia tridentata*)	Lassen	Sandy to clayey	8	Varies	Drought tolerant; high-quality browse.

* Ppt. = precipitation.
† PLS = pure live seed.

Table 4. Season of use for selected forage (native and nonnative) species (Holzworth et al. 2000)

Native	Nonnative	Spring	Summer	Fall	Winter
Sandberg's Bluegrass		X			
Big Bluegrass					
Squirreltail					
Bluebunch Wheatgrass	Tall Wheatgrass	X	X		
Beardless Wheatgrass	Intermediate Wheatgrass				
Streambank Wheatgrass					
Thickspike Wheatgrass					
Prairie Junegrass					
Thurber's Needlegrass					
Sand Dropseed					
Idaho Fescue	Pubescent Wheatgrass	X	X	X	
	Orchardgrass				
	Alfalfa				
	Sanfoin				
Basin Wildrye	Crested Wheatgrass	X			X
Needle-and-Thread					
Western Wheatgrass	Russian Wildrye		X	X	X
	Meadow Brome				
	Small Burnet	X	X	X	X
Slender Wheatgrass		X	X		X
Indian Ricegrass					

Table 5. Comparison of two seed lots for quality and value

	Seed lot A	Seed lot B
Cost/lb (bulk)	$1.75	$2.00
Purity	80%	95%
Germination	75%	90%
Pure Live Seed	55%	82%

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Appendix—Roadside Revegetation

Roadside revegetation sometimes has limited long-term success because many roadsides have low fertility and depleted biological activity. Poor nutrient cycling capacity results in inadequate retention of natural or amended nutrients. This reduces the establishment and persistence of vegetative stands.

Topsoil contains potentially valuable microorganisms, invertebrates, and living plant propagules. Biological activity in this zone cycles soil nutrients and increases nutrient availability, aerates the soil, maintains soil structure, and increases soil water-holding capacity. Topsoil additions can serve as a source of nutrients and mycorrhizal inoculum for revegetation of biologically inactive and nutrient-poor construction fill materials. Reapplication of healthy topsoil increases the chances of revegetation success and promotes establishment of persistent vegetative cover.

Roadsides act as weed pathways where repeated seed introductions from vehicle transport and frequent disturbances from roadside activities promote weed establishment. Delaying revegetation is not advised given the likelihood of rapid weed establishment. When selecting plant materials, consider the ability of the species to adapt to the site, rapidly establish, and self-perpetuate. Also, consider the species' abilities to compete with invasive weeds and produce extensive root systems to guard against soil erosion. Most rhizomatous species are tolerant of roadside disturbances.

Whenever practicable, select and distribute native, short-growing species for ecological reasons and to reduce long-term mowing maintenance. As with any successful revegetation effort, vigilant monitoring will be necessary to quickly identify invasive weeds and other problems and make timely corrections. Moreover, integrated roadside vegetation management practices that favor the seeded species are essential.

Integrated roadside vegetation management (IRVM)

With roadsides throughout the Great Basin occupying hundreds of thousands of acres, State and county road departments are large-scale vegetation managers. Roadsides should be managed cost-effectively to protect this public investment with minimal negative impacts on the environment. Integrated roadside vegetation management (IRVM) accomplishes this by establishing and maintaining long-term, low-maintenance, self-sustaining roadside plant communities. These plant communities maintain, restore, and enhance roadside functions while reducing weed encroachment. Management tactics are site specific and herbicides are used only when necessary.

An IRVM plan promotes the development and maintenance of functionally diverse roadside plant communities. Such communities reduce herbicide use because few resources are available to potential invaders. To encourage growth and vigor in roadside vegetation and to further maximize resource competition with weeds, mechanically mow roadsides only when necessary and avoid chemical mowing.

Chemical mowing

Chemical mowing is the application of nonselective herbicides broadcast to suppress the growth of roadside vegetation. Once believed to be far less disruptive and more economical than the mowers it replaced, chemical mowing is not recommended anymore because it can permanently damage desired roadside plants. However, chemical mowing may result in the spread of weeds by reducing desired plant competitiveness.

Mechanical mowing

Mechanical mowing is an important part of roadside maintenance. Proper mowing of certain roadsides is needed to maintain adequate sight distances for motorists and clear zones for errant vehicles to use. However, in many cases, mowing is performed indiscriminately or too often. This wastes public resources and can negatively affect desired vegetation, resulting in high-maintenance roadsides. Encourage the growth and vigor of desired roadside vegetation by mechanically mowing roadsides only when necessary.

To maintain adequate sight distances and clear zones, it may be necessary to mow roadsides mechanically along State or county roads, especially those that have underdeveloped shoulders. Mow to a height of 8 inches during the active growing season. This will promote desired vegetative vigor and continued resource capture. During the dormant period, which for most cool-season grasses begins after mid-July, mowing to 2 inches is acceptable because grasses are more tolerant during this time. It is not necessary to mechanically mow roadsides for aesthetic purposes when the road has a wide, developed shoulder.

Mowing and weeds

Besides affecting the competitive vigor of desired vegetation, improper timing of mechanical mowing can also facilitate the spread of invasive weeds. This can occur when roadsides are mowed with flail mowers after weed seeds have matured. Similarly, many roadside maintenance programs mow healthy roadside communities before desired seeds mature. This inhibits desired seed dispersal for the next year's stand while flail mowers expose the soil for weed seed, providing a competitive advantage for the weeds and cultivating even more weeds to manage in the future. Avoid any activities that give weeds an opportunity to spread.

However, by favoring desired-plant growth and decreasing the competitive vigor of weeds, properly timed mechanical mowing can be an effective weed management tool. This timing is based primarily on the growth stage of the weeds and, secondarily, on the growth stage of the desired plants.

The most effective time to mow invasive weeds is when the desired plants are dormant and the weeds have reached the flowering stage, well before seed production. Mowing at this time can encourage unrestricted growth and seed production of desired plants. It can also weaken the weeds and prevent them from producing seed. Long-term, repeated mowing of weeds after they have invested a large amount of energy in bolting (when the stem extends from the center of the rosette) and producing reproductive structures can eventually deplete root reserves and weaken the infestation. If regrowth bolts again and produces flowers, an additional mowing will be necessary.

When the dominant vegetation is an invasive weed, mow 2 inches high when the weed is between the early bud and early flowering stages. However, in some cases, weeds reach the appropriate stage for mowing before the grasses have reached dormancy. If so, mow the weeds at a height above the desired plants. Mowing above the height of actively growing grasses allows continued vigor, and defoliating the weeds reduces seed production and plant vigor, thereby, increasing the resources available for neighboring grasses.

Carefully timed roadside mowing may reduce the density and diminish the soil seed bank of weeds through attrition. Mowing was found to decrease spotted knapweed density by 85 percent when performed during the early bud stage. A further reduction in density can be anticipated when a herbicide treatment is applied to the rapidly developing weed regrowth 1 month after mowing.

Consider mowing and applying a herbicide in a single entry with a wet-blade mower. This mower's blade cuts the plants while applying a herbicide. Cavitation pulls the herbicide into the stem and the herbicide then moves into the plant's vascular system. Because the blade precisely places the herbicide only on the stems of the cut plants, the advantages of wet-blade mowing include reduced herbicide rates, runoff, and drift. Excellent results have been documented with many noxious weeds including Canada thistle *(Cirsium arvense)*, Dalmatian toadflax *(Linaria dalmatica)*, leafy spurge *(Euphorbia esula)*, Russian knapweed *(Acroptilon repens)*, and saltcedar *(Tamarix* spp.*)*.