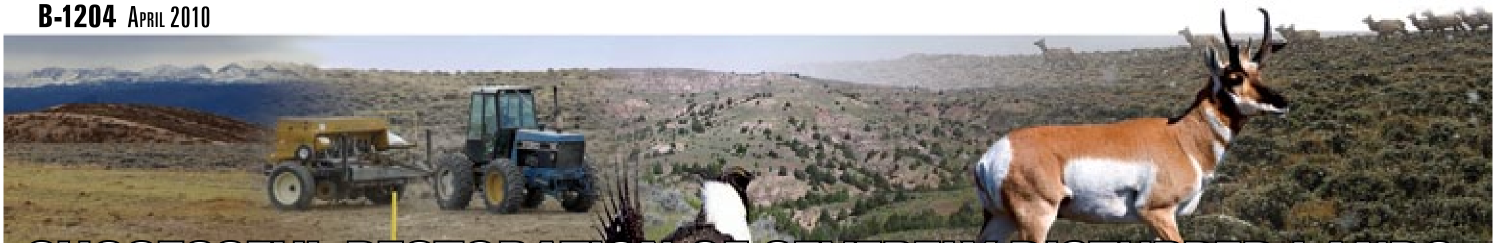


SUCCESSFUL RESTORATION OF SEVERELY DISTURBED LANDS: Seeding essentials for reclaiming disturbed lands

This bulletin provides general information appropriate for all Wyoming ecological sites.

Part of a series by the University of Wyoming Cooperative Extension Service Reclamation Issue Team and the Wyoming Reclamation and Restoration Center that describes strategies for restoring ecological functions to disturbed Wyoming lands.

Reclamation and restoration: For this series, **reclamation** means **restoration** of components that support desired ecological functions, such as livestock grazing, wildlife forage and cover, water supply, water quality protection, and aesthetic values.

Introduction

This bulletin provides information most relevant to revegetating disturbed grassland and shrubland plant communities in Wyoming. The information applies to sites drastically disturbed by mining or construction activities where topsoil has been stripped, stockpiled, and replaced.

Determine reclamation objectives

The goal for any reclamation project is to restore important pre-disturbance ecological functions of a site disturbed by construction or mining operations. Important functions include wildlife habitat, forage for livestock and wildlife, watershed and water quality protection, and others. A thorough pre-disturbance inventory provides the basis for describing important functions and setting reclamation objectives.

Summary of components of successful reclamation seeding. See text for more information.

Activity	Critical components

Design a reclamation seed mix	• Determine reclamation objectives.
	• Assess site-specific pre-disturbance vegetation characteristics (e.g., canopy cover of herbaceous species, shrub density).
	• Utilize site-specific Natural Resources Conservation Service (NRCS) Ecological Site Descriptions (ESDs) for lists of appropriate species.
	• Calculate seeding rates in mixes using the NRCS worksheet available on the Wyoming Reclamation and Restoration Center Web site (http://uwyo.edu/WRRC) under Reclamation Information (see also Table 2).
	    • Double that rate for "critical" (steep or unstable) sites.
	    • Double the drill rate for broadcast seeding (i.e., a steeply sloping, broadcast-seeded site would require 80 seeds per square foot).
	• Sagebrush: plant at ¼ to 1 pound per acre.
	• Native annuals: 1 ounce to 2.5 lbs per acre depending on seed size.
	• Consult local range specialists from the University of Wyoming Cooperative Extension Service (UWCES), NRCS, Bureau of Land Management (BLM), Forest Service, the Wyoming Department of Environmental Quality, Land Quality Division, or other local experts on native vegetation.

Prepare a firm seedbed	• Work the soil at about 10-15 percent moisture content or when a weak ball can be formed. • **Subsoil tillage** if necessary to restore drainage properties of compacted subsoils or underlying materials: deep rip 12- to 24-inch depth with 12 to 30 inches between shanks. Cross rip especially compacted sites. • **Primary tillage** to 10 to 24 inches following topsoil replacement if necessary to restore good drainage in compacted subsoils: deep rip with 30 inches between shanks or deep chisel. • **Secondary tillage** with disk, chisel plow, or moldboard plow to 6 to 12 inches, but not deeper than depth of replaced topsoil if necessary to break up large clods. Run across slope or perpendicular to prevailing wind to reduce erosion when soil moisture is 10 to 15 percent. • **Final tillage** for a firm seed bed free of large clods. Complete just before seeding because the smooth, firm seedbed is vulnerable to erosion. One or more passes with a cultipacker, roller harrow, springtooth harrow, clodbuster, or other surface preparation implement is recommended.

Use the best planting methods	• Ensuring proper seeding rates:
	• Calibrate seed drills or broadcast seeders;
	• Use properly designed seed box agitators and/or carrier materials to ensure accurate seeding rates of small, fluffy native seeds;
	• **Timing:** Dormant seeding after October 15 before the ground freezes or before April 15;
	• **Seeding depth:**
	    • One-quarter to ½ inch for many grasses and large-seeded forbs: drill with positive depth control works best.
	    • One-eight inch or less for small-seeded shrubs and forbs: surface broadcast seeder followed by cultipacker works best.

SUCCESSFUL RESTORATION OF SEVERELY DISTURBED LANDS: Seeding essentials for reclaiming disturbed lands

Authors

Calvin Strom, University of Wyoming Extension Educator

Jay Norton, Assistant Professor, Department of Renewable Resources

Todd Loubsky, Former Research Associate, Wyoming Reclamation and Restoration Center

Table of Contents

Summary

Successful revegetation of disturbed plant communities is achieved by planting adapted species into a firm, weed-free seedbed at the correct depth and at the best time of year to utilize moisture and overcome seed dormancy. This bulletin summarizes scientific literature and documented experience on how to improve chances for successful germination in the unpredictable semiarid climate of Wyoming's sagebrush grasslands. Specifically, we'll cover how to 1) design a seed mix based on an inventory of the pre-disturbance plant community and on information in ecological site descriptions developed by the Natural Resources Conservation Service (NRCS); 2) prepare a seedbed ready for planting; and 3) use the best planting methods to achieve accurate seeding rates and depths at the best time of year to capitalize on moisture for germination and establishment.

This bulletin does not cover soil amendments or post-seeding monitoring and management activities, such as weed and erosion control, grazing, mowing, or other practices that support permanent establishment of long-term plant communities. Please check other bulletins in this series for information on those topics.

Introduction

Revegetating disturbed lands in the Intermountain West is a challenge; low and variable precipitation distributed through the year in a way thatmakes summer drought a normal occurrence along with thin soils, steep slopes, and the cold, windy climate, require not only adherence to proven components of success but also patience. Most native species in this environment are long-lived and slow to establish.

So what can be done to improve revegetation efforts? Although a great deal of practical knowledge and research contributes to general understanding of how to create the best chance for success, the high number of failures reflects the difficulty. It also suggests information on revegetating disturbed land is not easy to access or understand. Choosing the adapted varieties of plant species native to the site is the first crucial component of successful reclamation and starts with understanding the pre-disturbance ecological functions that need to be restored.

Designing a reclamation seed mix

Reclamation objective

The objective of reclamation is usually to restore pre-disturbance ecological functions that include wildlife habitat, forage production, and water quality protection, but especially long-term ecological stability and resistance to erosion and weed invasion (Whisenant, 1999). In certain cases, especially on degraded or weed-infested sites, the reclamation objective may be to enhance ecological functions not fulfilled in the pre-disturbance condition. Also, on some private land, one function, such as crop or forage production, may have a higher priority than others and may influence reclamation decisions.

In general, reestablishing a diverse native plant community of grasses, forbs, and shrubs supports restoration of important ecological functions (Tilman, 1996). Although often more difficult to establish than introduced species, natives have proven to be able to sustain multiple reclamation objectives in the long run (Richards et al., 1998; Tilman, 1996). An inventory of the pre-disturbance plant community provides a basis for setting reclamation objectives and for designing a reclamation seed mix.

Assess pre-disturbance plant community

Prior to disturbance, conduct a thorough inventory of the site to determine elevation, annual precipitation, timing of precipitation, growing season length, existing vegetation, soil depth and texture, and land form characteristics. The site inventory guides identification of the NRCS ecological site description. A separate bulletin in this series details components of predisturbance inventory. Sources of information and links are available on the WRRC Web site (http://uwyo.edu/wrrc) under Reclamation Information. Assessment of the pre-disturbance plant community is crucial to successfully revegetate a disturbance, and different approaches are recommended for each plant life form.

Grasses and forbs. Determining aerial cover by species is a fairly rapid and longstanding method for determining relative amounts of herbaceous (grass/grasslike and forbs) species in a plant community (Elzinga et al., 1998), but, like any method, requires knowledge of local native species. Aerial cover refers to the area plants cover as viewed from above. Density or frequency measurements may give a more accurate assessment of species populations but are often difficult and time-consuming for herbaceous vegetation.

Several excellent publications describe proven and efficient methods for assessing aerial cover (Elzinga et al., 1998; Interagency Technical Team, 1999). In data presented at the 2009 Petroleum Association of Wyoming Reclamation Conference, Schladweiler and others found that, of the methods they assessed, the point-intercept transect method was the most efficient for accuracy and time required for collecting and analyzing data. Booth et al. (2006) describe a rapid assessment method using digital photography. More information and downloadable software for that method is available at www.ars.usda.gov/services/software/download.htm?softwareid=254.

Shrubs. Density (counting the number of shrubs in a given area) is the best method for estimating shrub populations on a site. Shrubs are typically planted at prescribed rates much higher than is reflected by their density in plant communities because they are notoriously poor establishers and, once established, tend to self-thin to an optimal density in balance with competition for moisture on a given site (Booth, 2002).

While observations of the pre-disturbance plant community are very important for setting reclamation objectives and designing seed mixes to meet those objectives, it can be difficult to identify all the important species. Minor or short-lived species may not be represented but should still be included. Ecological site descriptions developed by NRCS range specialists are valuable tools for understanding plant communities and designing the best reclamation seed mixes.

Consult NRCS Ecological Site descriptions

Ecological site descriptions provide guidelines for what species should occur in plant communities in different rainfall zones and on different soil types. Biomass in pounds per acre for each species in the "historical climax plant community" (often referred to as the reference state or condition) is listed on ESDs by species (grass/grasslike, forb, shrub). To access ESDs, first determine which ecological site best represents the reclamation project. For portions of Wyoming, the NRCS developed keys to help determine which ESD to refer to for a given site. The keys are posted on the WRRC Web site under Reclamation Information. To use the keys, you'll need to know the NRCS Major Land Resource Area (MLRA) in which the site lies (see Figure 2 and Table 1), as well as general information about the landscape position, soil depth, soil texture, and vegetation of the site.

Select adapted plant materials

To the extent possible, use seed that originates from the same soil and climatic conditions – the same ecotype – as the area to be planted. Any amount of proper seedbed preparation and management is a waste of time without use of adapted plant materials. Monsen and Stevens (2004) provide guidelines to species and ecotype selection. Plants from the same species that originate in different climates, on different soils, or even from far enough north or south to have a different day length, may not be adapted to the site you are reclaiming.

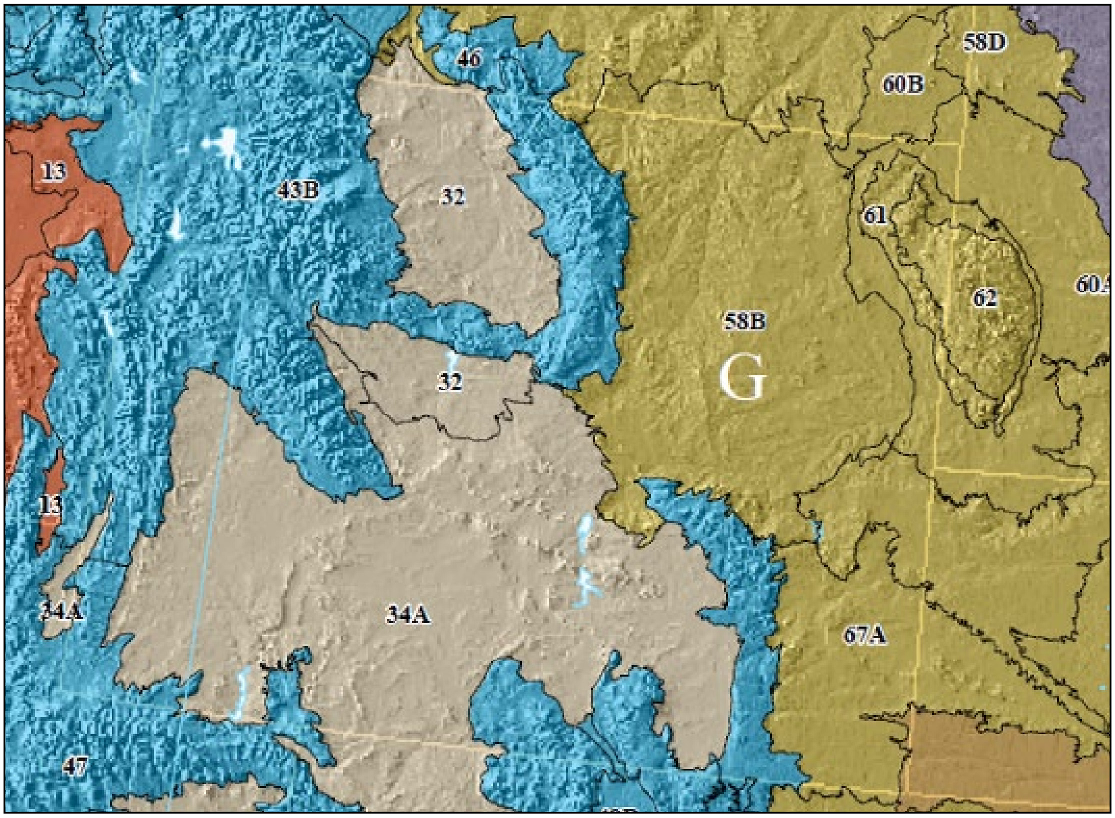


Figure 1. Wyoming Major Land Resource areas (USDA NRCS, 2006).

Table 1. Wyoming Major Land Resource Areas (USDA NRCS, 2006).

MLRA	Ecological Zones	Precipitation Zone (inches)
32 – Northern Intermountain Desertic Basins	Wind River and Big Horn Basins	5-9
	Wind River and Big Horn Basin Foothills	10-14
34A – Cool Central Desertic Basins and Plateaus	Green River and Great Divide Basins	7-9
	Foothills and Basins West	10-14
	High Plains Southeast	10-14
43B – Central Rocky Mountains	High Mountains	20+
	Foothills and Mountains, East, West and Northern Plains	15-19
49 – Southern Rocky Mountain Foothills	Foothills and Mountains, Southeast	15-19
58B – Northern Rolling High Plains, Southern Part	Northern Plains	15-17
	Powder River Basin	10-14
61 – Black Hills Foot Slopes	Black Hills	15-19
67A - Central High Plains, Northern Part	Southeastern Plains	12-17

Finding your Ecological Site Description

1. Once you've used the keys to determine the name of the ESD that applies (for example, Loamy 7-9" Green River and Great Divide Basin) you can find it on the Ecological Site Information System:
2. Go to: http://esis.sc.egov.usda.gov/ESIS/;
3. Click on Ecological Site Description in the center of the screen;
4. Click on Approved ESD Reports in the upper left;
5. Scroll down and, under State, select Wyoming and Submit.
6. Find the ESD and click on the ID;
7. Make sure your site lies within the area highlighted on the map, then click on Plant Communities along the left side of the screen;
8. This screen gives a great deal of information about interactions among rainfall, management, and plant community composition. Scroll down to see the state and transition model of plant community response to management and disturbance. Scroll down farther to see the list of plants and their high- and low-end production for the historical climax plant community. Compare this information to your observations of the site and to availability of seed to design a seed mix. Plant cover data does not directly correlate with the percent composition by weight data on the ESDs, but both provide similar information about plant community composition. Eventually, NRCS will include cover data on the ESDs.

Many reclamation species are available as several different varieties or germplasms. The species have been developed by plant breeders at universities, private firms, and USDA laboratories or through native collections tested by plant materials centers. Seed from superior plants is propagated under controlled conditions for sale as Foundation seed to qualified commercial seed producers. Other seed is harvested from natural wildland stands or seed production fields where no selection has been made. Unless you know you are buying from a reputable seller, it is an excellent idea to purchase seed that is either Certified or Source Identified by a seed certifying agency. Section V - *Vegetation in the Handbook of Western Reclamation Techniques* provides an excellent discussion of how to understand seed tests and order seed (Klienman, 1996). A link to the handbook is available on the WRRC Web site under Reclamation Information.

For much of Wyoming, big sagebrush and desert saltbushes are major components of the plant community, and it is especially crucial to purchase the correct subspecies of northern, locally adapted varieties (Dunne, 1996c; Lambert, 2005; Shaw et al., 2005). For big sagebrush, proper seed handling and cold storage below 38°F at 6 to 8 percent relative humidity can lengthen viability as much as five years, but improper handling, even for short periods, can result in rapid decline in viability and vigor (Shaw et al., 2005). Shaw et al. (2005) describe proper harvest and post-harvest handling procedures. Dunne (1996c) provides guidelines for purchasing shrub seeds for reclamation projects in Wyoming.

Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* Beetle & Young) is the most common big sagebrush subspecies in Wyoming. It is usually less than 3 feet tall and grows on shallow or droughty upland soils that receive 7 to 12 inches of precipitation. Basin big sagebrush (*Artemisia tridentata* ssp. *tridentata* Nutt.) is commonly up to 6 feet tall or taller and usually grows in deep loam, sandy loam, or silt loam soils in swales or along water courses and requires about 8 to 18 inches of precipitation. Mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana* [Rydb.] Beetle) is usually greater than 3 feet tall and grows on well-drained soils at higher elevations with at least 12 inches of precipitation (Lambert, 2005). Purchasing certified seed from seed orchards or purchasing common seed from reputable dealers are the only ways to ensure you are purchasing the proper subspecies for a particular site, although mountain big sagebrush is slightly heavier (fewer seeds per pound on average) (Lambert, 2005).

There are two categories of seed available on the commercial market: 1) traditional released varieties or cultivars that have been involved in purposeful selection may be genetically manipulated, and have proven superior or unique characteristics that are distinct, uniform, and stable, and, when reproduced, retain distinguishing traits; and 2) pre-variety seed that may not have been involved in purposeful selection, and the germplasm progressed through the system on a natural or manipulated track. The Association of Official Seed Certifying Agencies (AOSCA) verifies the status of commercially seed by using different colored tags. Two types of seed are most commonly available for reclamation projects: certified seed of a traditional released variety and cultivar and source-identified, pre-varietal seed.

Certified seed (blue tag): Purchase certified seed whenever possible. If seed lots for crops, shrubs, grasses, and forbs produced in Wyoming meet standards for genetic identity and purity, they can be certified by the University of Wyoming Seed Certification Service (Moore, 2008). The blue tag provides assurance that: 1) the species and variety are correctly identified and genetically pure; 2) the seed has high purity and germination that has been tested by a seed certification service seed lab; and 3) the bag has very few or no noxious weed seeds (Dunne, 1996a). Non-certified seed, called common or commercial seed, should also be tested for the purity and germination of the seed lot and to noxious weed-seed-free standards. This information is on the label, but there is no guarantee of the variety (Monsen and Stevens, 2004).

Source Identified (yellow tag): Source identified is a class of certified seed that verifies the collection site of native harvest seed (Dunne, 1996b). The seed certifying agency does an on-site inspection to verify the county and elevation of the collection site, but there is no guarantee that noxious weed seeds are not present. The supplier should have the seed tested for purity, germination, and weed seed content, which will be listed on the label. Discuss site conditions with seed suppliers to get the best available match and, whenever possible, use certified, source-identified seed that comes from an environment similar to your site. Lambert (2005) discusses the importance of using source identified seed, especially for big sagebrush.

For more information, there is a link to the AOSCA Native Plant Connection booklet on the WRRC Web page under Reclamation Information.

Proper seeding rates

The canopy cover data collected during pre-disturbance inventory or the biomass estimates from the ESD can be used to determine the percentage of species to be included in the seed mix. Big sagebrush and many annual native forbs are calculated at rates independent of pre-disturbance abundance because they are slow to establish and very dependent upon weather conditions.

Seeding rates depend on the type and size of seeds, seeding techniques, soil type, and moisture. It is important to use the correct seeding rate because too much seed is expensive and unnecessary, but too little seed limits the potential for a healthy plant community to establish. Monsen and Stevens (2004) explain higher seeding rates result in faster establishment and better competition with weeds, but lower rates result in more species in the mix being represented, if weeds are not a problem. They recommend a total of 8-16 pounds per acre for seeding a mixture of native grasses and forbs with higher rates for difficult, low-productivity sites and when broadcast seeding and lower rates for high-productivity sites and drill seeding. Schuman et al. (2005) report lower rates of grass seed result in better germination and establishment of Wyoming big sagebrush on Wyoming coal mine sites.

Based on long-term research and experience, NRCS recommends 20 pure-live-seeds per square foot for drill seedings of most species. This varies depending on the ease of establishment and aggressiveness of particular species (see Target Seeds/ft^2 in Table 2). NRCS recommends doubling the rate for broadcast seeding and for drill seeding critical area sites where germination is inhibited by low soil quality or other factors. Broadcast seeding critical area sites requires four times the target rate, according to these recommendations. Rates for each component of seed mixes are calculated as percentages of the target rate and then converting the number of seeds to weight of seeds using published values for the number of live seeds per pound for each species (see Table 2).

Seeding rate definitions

The tag on a bag of certified seed provides the net weight, the percentage purity, and the percentage germination.

Net weight: the total weight of seed + inert material (dust, chaff, empty seed, weed seed, etc.).
Purity: the percentage of total weight consisting of actual seed.
Germination: the percentage of actual viable seed.
Pure Live Seed (PLS): Purity x Germination100 = the percentage of the seed which is viable seed.

For example, to compare the cost of PLS in two bags of bulk seed:
Bag 1 is labeled 98% pure with 95% germination and at a cost of $5 per bulk pound.
Bag 2 is labeled 89% pure with germination of 92% at a cost of $ 4.75 per bulk pound.
Bag 1:98 x 95/100 = 93.10 PLS
Bag 2:89 x 92/100 = 81.88 PLS

Divide the seed cost by the PLS percentage to determine the Pure Live Seed cost:
Bag 1: $5 / 93.10 x 100 = $5.37 per PLS pound
Bag 2: $4.75 / 81.90 x 100= $5.80 per PLS pound

In addition, if the seed is to be planted at 5 PLS pounds/acre:
Bag 1: $5.37 X 5 = $26.85/acre
Bag 2: $5.80 X 5 - $29/acre
Using seed with a lower PLS rating will require more seed to be planted/acre.
Bag 1: 5 PLS lbs. per acre/0.931 = 5.37 bulk pounds to be planted
Bag 2: 5 PLS lbs. per acre/0.819 = 6.10 bulk pounds to be planted

Using the NRCS Conservation Cover Work Sheet

The NRCS Conservation Cover Work Sheet from the Electronic Field Office Technical Guide is a convenient tool for calculating seed mixes. The "Seed List" tab at bottom shows the list of species included and the information used to calculate seeding rates. You can change the information on the purity, germination, price, or price basis (bulk or PLS) to reflect values from a seed vendor. To use the worksheet to design a seed mix, click on the "Seed Calculator" tab, then:

1. Set the site and seeding parameter at the bottom by selecting the yellow cell and selecting the proper information from the drop-down lists. Parameters include precipitation zone, broadcast (Y or N), irrigation (Y or N), soil limitations, and drill spacing;
2. Next, click on a cell under "Species/Variety" and then click on the down arrow that appears and select a species from the drop-down list. Only species adapted to the parameters you set are listed;
3. Adjust the "Percent of Mix" to your preference. When you select a species and determine the proportion of the mix, the worksheet inserts information on that species based on seed size, PLS, and price information shown on the "Seed List" tab.

Go to www.uwyo.edu/wrrc and click on the Reclamation Information link then on the NRCS seeding worksheet.

Table 2. Characteristics of selected native species adapted. From NRCS Conservation Cover Worksheet

(see WRRC Web site-Reclamation Information). Also see PMC MT-46 (ftp://ftp-fc.sc.egov.usda.gov/MT/www/technical/plants/technotes/pm-technoteMT46.pdf)

	Seeds/lb†	Seeds/ft² @1lb/ac	Target Seeds/ft²§	Precip. Zone (inches)	Soil Type††	Planting Depth (inches)	Life Form	Longevity
Alkaligrass	2,108,000	48.4	48				Bunch	
Antelope Bitterbrush	21,000	0.5	10	10+	cl-sl	1/4-1/2	Shrub	Long
Balsamroot, Arrowleaf	55,000	1.3	10	10+	sil-sl	1/4-1/2	Erect	Long
Beeplant/Spiderflower	65,900	1.5	10	10+		1/4-1/2	Erect	Med
Bluegrass, Big	917,000	21.1	42	9-18	cl-sl	1/4-1/2	Bunch	Med
Bluegrass, Sandberg	900,000	20.1	40	5-18	cl-sl	0-1/4	Bunch	Med
Brome, Mountain	64,000	1.5	10	16+	c-sl	1/4-1/2	Bunch	Short
Buffaloberry, Silver	61,000	1.4	10	12-20	cs	plant	Shrub	Long
Fourwing Saltbush	55,000	1.3	10	8-16	l-s	1/8-1/2	Shrub	Long
Galleta	159,000	3.7	20	8-12		1/8-1/4	Bunch	Med
Globemallow	500,000	11.5	34	8+	saline	1/4-1/2	Erect	Long
Golden Current	356,000	8.2	25	12+	sil-sl	1/4-1/2	Shrub	Long
Hairgrass, Tufted	2,500,000	57.4	57	20+	c-sl	0-1/4	Bunch	Long
Lewis Flax	286,000	6.6	26	10+	sil-sl	0-1/8	Erect	Short
Mannagrass, Western	200,000	4.6	23	18+			Sod	
Mountain Lupine	12,000	0.3	10	16+			Erect	Short
Mountain Mahogony	52,000	1.2	10	14+	rocky	1/4-1/2	Shrub	Long
Needle and thread	150,000	3.4	21	8-20	cl-sl	1/4-1/2	Bunch	Short
Penstemon, Firecracker	600,000	13.8	34	8-20	cl-sl	1/8-1/4	Erect	Med.
Penstemon, Palmer	600,000	13.8	34	8-20	cl-sl	1/8-1/4	Erect	Med
Penstemon, Rocky Mtn.	280,000	6.4	26	8-20	cl-sl	1/8-1/4	Erect	Med
Rabbitbrush, Rubber	756,000	17.4	35	10+	sil-s	1/4-1/2	Shrub	Long
Ricegrass, Indian	162,000	3.7	20	10+	l-s	1/2-3	Bunch	Short
Rocky Mountain Juniper	27,100	0.6	10				Shrub	Long
Sacaton, Alkali	1,742,000	40.0	50	10+	wet	1/8-1/2	Bunch	Long
Sagebrush, Mountain	2,500,000	57.4	57	14+	cl-sl	0-1/8	Shrub	Long
Sagebrush, Wyoming Big	2,500,000	57.4	57	8-16	cl-sl	0-1/8	Shrub	Long
Saltgrass, Inland	672,000	15.4	35	8+	saline	1/8-1/2	Sod	Long
Serviceberry, Saskatoon	45,000	1.0	10	12+	sil-sl	1/4-1/2	Shrub	Long
Shadscale	65,000	1.5	10	6-16			Shrub	Long
Skunkbush Sumac	19,000	0.4	10	14+	course	1/4-1/2	Shrub	Long
Snowberry	54,000	1.2	10	14+	sil-sl	1/4-1/2	Shrub	Long
Squirreltail, Bottlebrush	192,000	4.4	20	8-20	cl-sl	1/4-1/2	Bunch	Long
Sweetvetch, Utah	35,000	0.8	10	10+	cl-sl	1/8-1/4	Erect	Med
Western Yarrow	4,124,000	94.7	64	10+	cl-sl	0-1/4	Prostrate	Med
Wheatgrass, Bluebunch	126,000	2.9	20	8+	cl-sl	1/4-1/2	Bunch	Long
Wheatgrass, Slender	133,000	3.1	20	10+	c-sl	1/4-1/2	Bunch	Short
Wheatgrass, Thickspike	156,000	3.6	20	8+	l-s	1/4-1/2	Sod	Long
Wheatgrass, Western	114,000	2.6	20	12+	cl-sl	1/4-1/2	Sod	Long
Wildrye, Beardless	51,000	1.2	10	14+	wet/ saline	1/4-1/2	Sod	Long
Wildrye, Great Basin	144,000	3.3	20	12+	sil-sl	1/4-1/2	Bunch	Long
Winterfat	112,000	2.6	21	8+	limy	1/8-1/4	Half Shrub	Long

† Averages. Actual number of seeds per pound varies depending on the growing conditions of the site and in the production year.
§ Recommended rates for full stands based on ease of establishment and aggressiveness. Divide by desired percent in stand to calculate seeds per square foot of each species in mix (see text box on calculating seeding rates).
†† cl, clay loam; sl, silt loam; sil, silt; c, clay; cs, coarse sand; l, loam; s, sand; sl, sandy loam; cl, clay loam

Calculating seeding rates

To use the information in Table 2 to calculate seeding rates, multiply the percent of each species in the mix by the total target seeds per square foot to get the seeds per square foot for each species. Divide that value by the seeds per square foot at 1 pound per acre for each species. For example, if bluebunch wheatgrass (bbwg) seed is to make up 23 percent of a seed mix that will be drill seeded on a flat site with loam soil:

20 seeds/ft^2 x 0.23 = 4.6 bbwg seeds/ft^2

4.6 bbwg seeds/ft^2 ÷ 2.9 seeds/ft^2 @ 1 PLS lb/acre = 1.6 PLS lbs bbwg seed/acre in the mix.

For big sagebrush, Booth and Bai (2000) recommend planting about 100 pure live seeds per square foot (about 1.7 PLS pounds per acre). NRCS recommends about 57 seeds per square foot (about 1 PLS pound per acre). High seeding rates are consistent with sagebrush ecology because mature sagebrush plants can produce 500,000 seeds per year, but annual production varies a great deal (Shaw et al., 2005). The weight of big sagebrush seeds also varies a great deal, with heavier seed having higher vigor. Booth and Bai (2000) found that seed from lots with less than 1,600,000 seeds per pound had higher vigor than seed from lighter lots. They recommend that, whenever possible, purchasers request seeds from heavier lots.

A portion of big sagebrush seed remains viable beyond the seeding year, so the higher the seeding rate, the longer an adequate portion of the seed bank will remain viable until a good germination year occurs (Schuman et al., 2000).

Purchasing mixes of adapted, certified, or pre-varietal source-identified seed is necessary for successful restoration of pre-disturbance site functions but is a waste of money without proper seedbed preparation and precise seed placement at the right time of year.

Prepare a firm seedbed free of large clods

Proper seedbed preparation results in a seedbed free of competition from established weeds, a friable structure allowing infiltration of moisture, yet does not puddle, and is firm below the seeding depth to hold moisture for root development (Monsen and Stevens, 2004). While restoration of sites chronically disturbed by overgrazing or noxious weed invasion, where topsoil has not been removed, can often be no-till seeded, sites drastically disturbed by construction and extraction activities may require multiple tillage operations with heavy equipment to prepare a suitable seedbed. Although the resulting physical soil conditions are often different from the pre-disturbance conditions, seedbed preparation that enhances germination and establishment will speed restoration of pre-disturbance conditions.

According to the *Handbook of western reclamation techniques*, the result of proper seedbed preparation is an absence of clods more than 3 inches in diameter in a seedbed where a 170-pound person leaves footprints no deeper than ¾ inch, and ridges from cultipacking are no higher than two inches (Steward and Hansen, 1996). NRCS generally recommends no clods more than 2 inches in diameter and that a 170-pound person leaves footprints no deeper than ½ inch.

On construction sites where topsoils are removed and stockpiled, subsoils and underlying materials often become compacted during construction activities, reducing the water infiltration and holding attributes of the soil. If this is the case, the first tillage operation should be deep ripping to 12 to 24 inches prior to respreading topsoil.

Once a site is recontoured, ripped as necessary, and topsoil respread, three stages of tillage may be needed to ensure an ideal seedbed: 1) primary tillage to develop good drainage and alleviate compaction; 2) secondary tillage to break large clods and improve infiltration; and 3) finish tillage to further break clods and firm the seedbed for planting.

Primary tillage to 10 to 24 inches deep may be necessary to alleviate compaction caused during topsoil respreading. Mixing subsoils and topsoils should be avoided by using implements that do not turn over the soil. Tools include subsoil rippers for the deepest tillage (12-24 inches) with at least 30 inches between shanks (Figure 2a), chisel plows for 10-18-inch tillage with about

A B C

Figure 2. Primary tillage implements: (a) deep ripper (Calvin Strom)**, (b) deep chisel** (B.W. Implement, www.bwimp.com)**, and (c) deep disk** (B.W. Implement, www.bwimp.com).

A B C

Figure 3. **Secondary tillage implements: (a) disking** (B.W. Implement, www.bwimp.com), **(b) chisel plow** (Buckeye Tractor Co., www.buctraco.com), **and (c) moldboard plow** (University of Nebraska-Lincoln, M. Mamo).

12 inches between shanks (Figure 2b), or offset disks for 10-14-inch tillage (Figure 2c). Offset disks should not be used at depths deeper than the thickness of the respread topsoil.

Secondary tillage to 6 to 12 inches aerates respread topsoils, breaks up clods, buries weed seeds (disk or moldboard plow only), and incorporates any plant residues or amendments. Secondary tillage operations include disking to 6-10 inches (Figure 3a), chisel plowing to 6-10 inches (Figure 3b), or moldboard plowing to 6-12 inches (Figure 3c). Secondary tillage should not be done to depths deeper than the thickness of the respread topsoil.

The goal of finish tillage is to develop a firm seedbed free of large clods and ready to plant. Finish tillage involves one or more passes with a cultipacker (Figure 4a), roller harrow (Figure 4b), spring tooth harrow (Figure 4c), clodbuster (Figure 4d), or other light surface tillage implements. The modern no-till range drills may eliminate the need for finish tillage because they have press wheels that firm the seedbed directly over the seed. In this case, leaving a rougher seed bed is desirable because roughness decreases wind and water erosion and captures moisture from snow.

The Ideal Seedbed (Valentine, 1989):

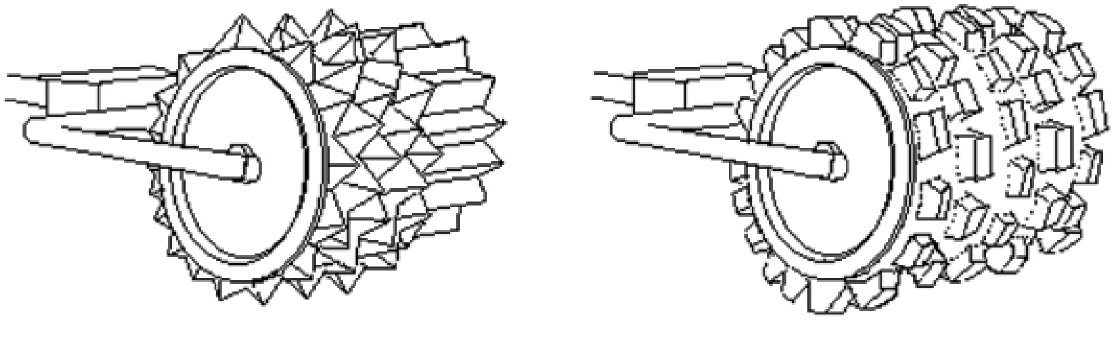
1. Firm below seeding depth.
2. Free of large clods and smooth.
3. No clodding or puddling.
4. Free from live resident plant competition.
5. Free of seed from competitive species.

Seedbed preparation works best at a soil moisture content of about 10 to 15 percent (Wright and White, 2000), or when a weak ball can be formed from soil 2 to 3 inches below the surface. At this moisture content, soils are typically loose and friable so soil structure resists tillage. Working dry soil pulverizes it to the consistency of flour and increases losses to wind erosion, especially losses of soil organic matter. Working wet soil results in compaction, clodding, and loss of good drainage properties.

Once the seedbed has been packed and seeded, roughening the soil surface by creating furrows or pits with implements like rollers or imprinters (Figure 5) can increase moisture infiltration, capture blowing snow, and slow the surface velocity of wind and water, reducing erosion and sedimentation (Branson et al., 1966; Neff, 1980; Valentine, 1989).

A B C D

Figure 4. **Finish tillage implements: (a) cultipacker** (Michigan State University), **(b) roller harrow** (Hobby Horse Ranch L.L.C., www.hobbyhorseranch.com), **(c) spring tooth harrow** (Iowa State University, G. Tylka), **and (d) clodbuster** (Sam Fortenberry Auctioneers, Lockney, TX).



Three types of Texturing Rollers

Sheep's foot (upper R) This system uses a series of studs to imprint depressions into the soil.
Imprinter (upper L) This system uses specially designed teeth to press into the soil. These teeth create depressions for water retention in arid soils.

Grid Roller (lower R) Made up of heavy steel rod in a basket weave. Impresses grooves and raised knobs into soil surfave.

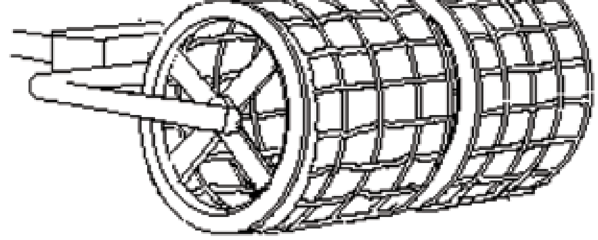


Figure 5. Texturing rollers create a rough surface that captures runoff and blowing snow and reduces wind erosion (Graber, 1999).

Furrows or pits might be especially effective for saline soils because they can reduce salinity at the soil-seed interface as higher evaporation rates on the ridges draw salt upward by capillary action. This results in the salt concentrating in the ridges away from the seed in the furrow (Koehler, 1975).

Use the best planting methods

Several different types of equipment are available for seeding grasses, forbs, and shrubs onto reclamation projects, including drill seeders, broadcast seeders, hydromulch seeders, and aerial seeding. Aerial seeding is most useful for large-scale rehabilitation projects, such as following wildfires in steep terrain (Lysne and Pellant, 2004) and will not be discussed in this bulletin.

The size and accessibility of the seeding project and the recommended depth of seed to be planted determine the type of equipment that should be used (see Table 2). Seed drills (Figure 6) are the preferred method for most grasses and large-seeded shrubs and forbs that need to be planted at least ¼-inch deep because drills enable positive depth control, firm seed-soil contact, and, once calibrated, proper seeding rates. Broadcast seeders are preferred for very small seeds that need to be planted 1/16-to 1/8-inches deep. Pull-type seeder-packers (Figure 7b) are excellent for shallow-seeding shrub and forb seeds, while truck- or tractor-mounted broadcaster seeders are often used for seeding shrub seeds over snow. Hand-held broadcasters (Figure 7a) work well for small or steeply sloping sites.

Hydromulch seeders (Figure 8) and aerial seeding are much less effective but may be the only option for difficult-to-access sites. Whatever the method, it's crucial to plant seeds at the right time of year to optimize moisture availability during germination.

Time planting to optimize moisture

Dormant seeding between October 15 and April 15 is most effective across Wyoming because early spring is the most reliable period for moist soil conditions. Even though many long-term weather stations report that summer months receive more precipitation on average, the low temperatures and dormant vegetation in winter cause low evapotranspiration rates so that moisture accumulates to create moist soils in the spring even if the winter is abnormally dry (Western Regional Climate Center, 2009).

Dormant seeding is done late enough in the year to prevent germination until the following spring (i.e., soil temperatures should be less than 40 degrees at 2 inches depth) (Holzworth and Wiesner, 2007). Late fall planting also helps native species overcome dormancy through cold stratification, which is necessary for some species to germinate. While seeding in spring, summer, or early fall can be successful, it is a much bigger gamble than dormant seeding. By the time the soil dries in the spring sufficiently to avoid damaging the seedbed, much of the valuable moisture accumulated over the winter has been lost to evaporation or weeds. Spring and summer rainfall is unpredictable, and soils usually dry out rapidly following precipitation events. Seeds planted in spring or summer often begin to germinate following rainfall, only to desiccate and die during subsequent dry weather. The risk associated with early fall planting is warm, moist weather that can cause seeds to begin to germinate before freeze up. Most small, freshly germinated seedlings can't survive Wyoming winters. An exception is that some forbs can begin to germinate very rapidly and therefore are better suited to spring than fall seedings. If seedbeds, are ready for planting in the spring, but fall planting is preferred, NRCS recommends planting a cover crop such as sterile triticale or other small grain to protect the site from erosion.

While the general recommendation for planting big sagebrush is also late fall (Lambert, 2005), many practitioners report success with late winter or early spring (February or March) broadcast seeding on top of the snow. This is an opportunistic approach that requires the flexibility to act when conditions are just right for accessing the site and operating seeding equipment.

Seed drills

Using a seed drill (Figure 6) is preferred when there is a fairly flat, smooth seedbed and relatively large seeds are being planted (Munshower, 1994). To be most effective, drill seeding should be done on the contour and perpendicular to prevailing winds. A cultipacker is often used to firm the seedbed after the seeds are placed in the ground, but many drills have press wheels that firm the soil over the seed furrow using the weight of the drill. Seed drills require the minimum amount of seed, and they provide the best seed-to-soil contact and depth control. Modern rangeland drills continue to improve and have features such as multiple boxes for different seed types, the ability to seed at more than one depth for different seeds or to broadcast and drill at the same time, and agitators that prevent bridging and clogging by fluffy native seeds. Older agricultural drills originally designed for seeding grain lack positive depth control, packing wheels, and other features crucial to successful revegetation. Older drills can be used, but care should be taken to ensure the components of success – proper depth, proper rate, and firm seed-soil contact – are met.

St. John et al. (2004) provide a guide to calibration of seed drills, which is crucial to ensure proper seeding rates of native seeds. Even when drills are properly calibrated, native seeds pose several challenges for achieving consistent seeding rates. Native seeds are often very small and may have long awns or fuzzy coatings that cause bridging and blockage in seed boxes and tubes. Purchasing processed seed with awns removed can help, as can seed boxes with agitators designed to prevent bridging.

Figure 6. Seed drill (Calvin Strom).

Native forbs and shrubs often have extremely small and fluffy seeds that are difficult to plant. Thorough mixing with an inert carrier, such as rice hulls, cracked grain, vermiculite, coarse sand, or granular clay products (kitty litter, Shop Dry) can improve distribution of seeds (St. John et al., 2005). St. John et al. (2005) report rice hulls are the most inexpensive and effective seed carrier. They also explain how to calculate proportions of seed and rice hulls in mixtures.

Row spacing varies among seed drills and is usually adjustable from about 8 to 10 inches to multiples of that by blocking alternate rows. Narrower spacing results in greater initial production and better competition with weeds, but differences disappear in later years (Monsen & Stevens, 2004). Some forbs, such as globemallow and lupine, benefit from wider row spacing. Some drills allow seeds to be metered at different rates for each seed drop. This allows separate or alternate row seedings where the seed boxes are divided into sections and grass seed mixes planted are in separate rows from forb and shrub mixes (Monsen & Stevens, 2004). On drills not capable of crop-specific seeding rates, carriers must be added to dilute the material and regulate the amount of seed sown.

Broadcast seeders

Broadcasting is the preferred seeding method for steep slopes or rough terrain, fluffy, uneven, or trashy seed, and very small-seeded species; however, a considerable drawback is that predation of seed by rodents and birds, as well as movement and desiccation by wind and sun, can result in lower germination rates compared to drill seeding. Hence the double rate recommended by NRCS.

A B

Figure 7. Hand broadcast seeding (a) (Montana State University, 2009) **and a Brillion seeder (b)** (Montana State University, 2009).

In a large NRCS field evaluation planting, forb species performance of the drill-seeded plots was substantially lower than in the broadcast-seeded plots, suggesting seeding depth is an important factor for many of the small-seeded species (Winslow et al., 2008).

Broadcast seeding involves dispersing seed on top of the soil rather than burying it under the soil. Broadcasting is a low-cost and rapid method of seeding; however, due to the seed being placed on top of the soil surface, it needs to be followed by an imprinter or drag (chain, harrows) to bury the seed and ensure good seed-to-soil contact. Some broadcast seeders, such as Brillion seeders (Figure 7b), have a built-in cultipacker. There are many different types of broadcast seeders available, from mechanical to manual devices depending on project size and site characteristics.

Hydromulch and hydroseeders

Hydroseeding involves dispersing seed with water and sometimes additives such as fertilizer. After hydroseeding, the seed is usually covered by another spray of mulch and tackifier (Parrish & Anderson, 1994). The use of mulch and tackifier (which binds the mulch and reduces mulch loss to wind and water) can also assist in stabilizing erosion-susceptible areas; however, tackifier may also reduce the ability of water to infiltrate the soil and thus limit seed germination (Munshower, 1994).

Site characteristics, such as steep slopes, rough terrain, or areas with problematic access, require the use of a seeding method done without machinery being driven over the site. In these instances, hydroseeding may be an effective seeding method. Drawbacks with this method compared to more conventional seeding methods include high cost, poor seed-soil contact, and the large amounts of water required (Whisenant, 1999).

Figure 8. Hydromulch seeder (Montana State University, 2009).

Results of NRCS trials suggest the one-step practice of hydroseeding may not be effective, mainly because of poor seed-soil contact, and should not be used except where other alternatives are impossible (Winslow et al., 2008).

Sources of reclamation seeds

Please refer to the following publications posted on the WRRC Web site, under Reclamation Information:

For vendors in Idaho, Montana, Nevada, Eastern Oregon, Utah, Eastern Washington, and Wyoming: TN Plant Materials No. 33, October 2009 Revision.

For vendors in Colorado: (forthcoming)

Sources of information

Four excellent, recent publications summarize the vast amount of research and knowledge on reclamation seeding in the semiarid western US:

Sagebrush establishment on mined lands: Ecology and research. 2001. G.E. Schuman, T.C. Richmond, and D.R. Neuman, eds. Proceedings of the Billings Land Reclamation Symposium, March 20-24, 2000, Billings, MT. http://www.techtransfer.osmre.gov/nttmainsite/Library/proceed/sagebrsh/frontmatter.pdf

Sage grouse habitat restoration symposium proceedings. 2005. N.L. Shaw, M. Pellant, S.B. Monsen, eds. Proceedings RMRS-P-38, Boise, ID, June 4–7, 2001. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO. http://www.fs.fed.us/rm/pubs/rmrs_p038.pdf.

Restoring western ranges and wildlands, volumes 1 to 3. S.B. Monsen, R. Stevens, and N.L. Shaw, eds. Gen. Tech. Reps . RMRS-GTR-136-vol-1, 2, and 3. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Volume 1: www.treesearch.fs.fed.us/pubs/7377

Volume 2: www.treesearch.fs.fed.us/pubs/7378

Volume 3: www.treesearch.fs.fed.us/pubs/7379

Handbook of western reclamation techniques. 1996. F.K. Ferris et al., eds. The Office of Technology Transfer, Western Regional Coordinating Center, Office of Surface Mining Reclamation and Enforcement, 1999 Broadway, Suite 3320, Denver, CO 80202-5733. www.techtransfer.osmre.gov/NTTMainSite/Library/hbmanual/westrecl/handbook.pdf.

Links

NRCS Plant Materials Centers at Bridger, Montana, and Aberdeen, Idaho, have lists of valuable publications, including "Technical Notes" and "Plant Guides":

Bridger PMC publications: http://plant-materials.nrcs.usda.gov/mtpmc/publications.html

Aberdeen PMC publications: http://plant-materials.nrcs.usda.gov/idpmc/publications.html

Native Plant Connection, Association of Official Seed Certifying Agencies, provides information on classes of seed available for commercial purchase:

www.aosca.org/aoscanativeplantbrochure.pdf

Wyoming Department of Environmental Quality, Land Quality Division Guidelines and Standard Operating Procedures for coal and noncoal operations provide valuable information on many aspects of reclamation: http://deq.state.wy.us/lqd/guidelines.asp.

Wyoming Reclamation and Restoration Center, provides information on the center's research and academic programs. Check the **References** tab for full text versions of most of the references in this bulletin and the **Reclamation Information** tab for supplemental information referred to in this bulletin. http://uwyo.edu/wrrc/.

References cited

Booth, D.T. 2002. Seed longevity and seeding strategies affect sagebrush revegetation. *Journal of Range Management* 55:188-193.

Booth, D.T., and Y. Bai. 2000. Seeds and seedling establishment of Wyoming big sagebrush, p. 24-31, *In* G. E. Schuman, et al., eds. Proceedings, "Sagebrush Establishment on Mined Lands," Billings Land Reclamation Symposium, March 20-24, 2000, Billings, MT.

Booth, D.T., S.E. Cox, and R.D. Berryman. 2006. Point sampling digital imagery with 'Samplepoint'. Environmental Monitoring and Management 123:97-108.

Branson, F.A., F.R. Miller, and I.S. McQueen. 1966. Contour furrowing, pitting and ripping on rangelands of the western United States. *Journal of Range Management* 19:182-190.

Dunne, C.G. 1996a. Certified blue-tag versus non-certified (common) seed, In L. H. Klienman, ed. Section V. Vegetation. *Handbook of western reclamation techniques*. Office of Surface Mining Reclamation and Enforcement, Denver, CO.

Dunne, C.G. 1996b. Source-identified yellow-tagged seed, In L. H. Klienman, ed. Section V. Vegetation. *Handbook of western reclamation techniques*. Office of Surface Mining Reclamation and Enforcement, Denver, CO.

Dunne, R. 1996c. Selecting good shrub seed, p. V-74, In L. H. Klienman, ed. Section V. Vegetation. *Handbook of western* *reclamation techniques*. Office of Surface Mining Reclamation and Enforcement, Denver, CO.

Elzinga, C.L., D.W. Salzer, and J.W. Willoughby. 1998. Measuring and monitoring plant populations. Bureau of Land Management Technical Reference 1730-1.

Graber, J. 1999. A guide to the revegetation and environmental restoration of closed landfills. California Integrated Waste Management Board, Publications Section. www.ciwmb.ca.gov/LEAcentral/Closure/Revegetate (October 12, 2009).

Holzworth, L., and L.E. Wiesner. 2007. Seedbed preparation and seeding technical note. United States Department of Agriculture Natural Resources Conservation Service Plant Materials Technical Note No. MT-58. April 2007.

Interagency Technical Team. 1999. Sampling vegetation attributes. BLM/RS/ST-96/002+1730, 176pp.

Klienman, L.H. 1996. Section V. Vegetation. *Handbook of western reclamation techniques*. Office of Surface Mining Reclamation and Enforcement, Denver, CO.

Koehler, D.A. 1975. A review of the literature on reseeding sagebrush-bunchgrass ranges in the semi-arid western United States. Oregon Wildlife Commission, Wildlife Res. Report No. 4.

Lambert, S.M. 2005. Seeding considerations in restoring big sagebrush habitat, p. 75-80, In N. L. Shaw, et al., eds. Sage grouse habitat restoration symposium proceedings; June 4-7, 2001,; Boise, ID. Proceedings RMRS-P-38. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Lysne, C.R., and M. Pellant. 2004. Establishment of aerially seeded big sagebrush following southern Idaho wildfires. Bureau of Land Management Technical Bulletin No. 2004-01.

Monsen, S.B., and R. Stevens. 2004. Seedbed preparation and seeding practices, p. 121-154, In S. B. Monsen, et al., eds. Restoring western ranges and wildlands, vol. 1. Gen. Tech. Rep. RMRS-GTR-136-vol-1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Montana State University. 2009. Ecosystem restoration photo tour (http://ecorestoration.montana.edu/mineland/photos/default.asp) [Online] (posted November 13, 2007; verified October 12).

Moore, M. 2008. Wyoming certified seed directory. University of Wyoming Seed Certification Service, Wyoming Crop Improvement Association, Powell, WY. http://www.wyseedcert.com.

Munshower, F.F. 1994. Practical handbook of disturbed land revegetation. CRC Press.

Neff, E.R. 1980. Snow trapping by contour furrows in southeastern Montana. *Journal of Range Management* 33:221-223.

Parrish, T.L., and S.H. Anderson. 1994. Handbook of methods to reclaim wildlife habitat on surface mines in Wyoming, pp. 129. Wyoming Cooperative Fish and Wildlife Research Unit, Laramie, WY.

Richards, R.T., J.C. Chambers, and C. Ross. 1998. Use of native plants on federal lands: Policy and practice. *Journal of Range Management* 51:625-632.

Schuman, G.E., D.T. Booth, and R.A. Olson. 2000. Enhancing Wyoming big sagebrush establishment with cultural practices, p. 32-42, In G. E. Schuman, et al., eds. Proceedings, "Sagebrush Establishment on Mined Lands," Billings Land Reclamation Symposium, March 20-24, 2000, Billings, MT.

Schuman, G.E., L.E. Vicklund, and S.E. Belden. 2005. Establishing *Artemisia tridentata* ssp. *wyomingensis* on mined lands: Science and economics. *Arid Land Research and Management* 19:353-362.

Shaw, N.L., A.M. DeBolt, and R. Rosentreter. 2005. Reseeding big sagebrush: Techniques and issues, p. 99-108, In N. L. Shaw, et al., eds. Sage grouse habitat restoration symposium proceedings; 2001 June 4–7; Boise, ID. Proceedings RMRS-P-38. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

St. John, L., D. Ogle, M.E. Majerus, and L. Holzworth. 2005. Mixing seed with rice hulls, Plant Materials Technical Note No. 7 (revised), USDA Natural Resources Conservation Service.

St. John, L., D. Ogle, L. Holzworth, M. Stannard, and J. Cornwell. 2004. Calibrating a seed drill for conservation plantings, Plant Materials Technical Note No. 7 (revised), USDA Natural Resources Conservation Service.

Steward, D.G., and M.M. Hansen. 1996. Cultivation practices, *In* L. H. Klienman, ed. Section V. Vegetation. Handbook of Western reclamation techniques. Office of Surface Mining Reclamation and Enforcement, Denver, CO.

Tilman, D. 1996. Biodiversity: Population versus ecosystem stability. *Ecology* 77:350-363.

USDA NRCS. 2006. Land Resource Regions and Major land Resource Areas of the United States, the Caribbean, and the Pacific Basin. Agriculture Handbook 296. U.S. Government Printing Office, Washington, DC. http://soils.usda.gov/survey/geography/mlra/.

Valentine, J.F. 1989. Range development and improvements. Brigham Young University Press, Provo, UT.

Western Regional Climate Center. 2009. Wyoming climate summary. http://www.wrcc.dri.edu/summary/Climsmwy.html [Online]. Available by Desert Research Institute.

Whisenant, S.G. 1999. Repairing damaged wildlands: A process-oriented, landscape-scale approach. Cambridge University Press, Cambridge.

Winslow, R.S., K.J. Clause, R. Hybner, and J. Jacobs. 2008. Evaluating seeding techniques and native plant establishment in the Pinedale Anticline, Wyoming. , *In* J. E. Brummer, ed. Proceedings, High Altitude Revegetation Workshop No. 18, March 4-6, 2008. Colorado Water Resources Research Institute, Information Series No. 107, Fort Collins, CO.

Wright, M.A., and S. White. 2000. Practical guide to reclamation in Utah. Utah Oil, Gas, and Mining Commission. https://fs.ogm.utah.gov/pub/MINES/Coal_Related/RecMan/Reclamation_Manual.pdf.

Acknowledgements

We appreciate careful review of this document by:

- Everet Bainter, Wyoming Rangeland Management Specialist, USDA Natural Resources Conservation Service, Casper, WY;Paul Griswold, Reclamation Specialist, Peabody Energy Company, Gillette, WY;
- Ania Krzyszowska-Waitkus, Soil Scientist, Wyoming Department of Environmental Quality, Land Quality Division, Cheyenne, WY;
- Karen Clause, Rangeland Management Specialist, USDA Natural Resources Conservation Service, Pinedale, WY;
- Pete Guernsey, Biologist/Ecologist, Questar Exploration and Production, Pinedale, WY;
- Micheal Smith, Professor, University of Wyoming Department of Renewable Resources;
- Roger Hybner, Susan Winslow, and Jim Jacobs, Bridger Plant Materials Center, Bridger, MT.

Senior Editor: Steven L. Miller, College of Agriculture and Natural Resources, Office of Communications and Technology
Graphic Designer: Bernadette van der Vliet, College of Agriculture and Natural Resources, Office of Communications and Technology

UNIVERSITY
OF WYOMING

Issued in furtherance of Cooperative Extension work, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Glen Whipple, Director, Cooperative Extension Service, University of Wyoming, Laramie, Wyoming 82071.