10 IMPLEMENTATION GUIDES

Chapter 10 details the practices common to most revegetation projects. It is divided into 19 subchapters, called implementation guides, which summarize the important information needed to execute each practice.

Implementation guides are grouped into four subject areas:

- 10.1 Soil and Site Treatments,
- 10.2 Obtaining Plant Materials,
- 10.3 Installing Plant Materials, and
- 10.4 Post Installation Care of Plant Materials.

The eight guides in Section 10.1, Soil and Site Treatments, explain how to improve site and soil conditions prior to the installation of plant materials. These guides cover the mitigating measures most often referenced in Chapter 5.

Section 10.2, Obtaining Plant Materials, covers six implementation guides that pertain to collecting and propagating plant materials. These guides describe how to take the species lists developed in Chapter 6 and obtain the desired species in the wild as seed, cuttings, or seedlings. These guides also cover how to increase gathered wild collections at nurseries to ensure that the revegetation project has sufficient quantities of plant materials.

Once plant materials are obtained from the wild or from nurseries, they are installed on the project site. The four guides in Section 10.3, Installing Plant Materials, cover the techniques for sowing seed, installing cuttings, and planting seedlings. They also cover how to determine the quality of the plant materials and how to care for them during storage and transportation.

Section 10.4, Post Installation Care of Plant Materials, outlines those practices that take place after the installation of plant materials. These practices help ensure that plants will become established. Practices include protecting seedlings from animal browsing, installing shade cards, irrigating, and installing tree shelters.

10.1 SOIL AND SITE TREATMENTS

Most post-construction sites are in poor condition for plant growth and will require the implementation of mitigating measures if full or even partial revegetation is expected. The following set of implementation guides cover the common mitigating measures for improving site conditions after construction. The implementation guide to fertilizers, Section 10.1.1, covers how to determine the quantity, type, and application method of fertilizers. Tillage, Section 10.1.2, describes the common practices of tilling the soil to improve water infiltration and root growing environment. Improving seed germination and reducing surface erosion can be accomplished through the application of mulches, which is detailed in Section 10.1.3, Mulches.

Section 10.1.4, Topsoil, outlines the removal, storage, and application of topsoil to reconstruct soil on highly disturbed sites. For sites where topsoil is not available or in short supply, organic matter can be applied to improve post-construction soils. Section 10.1.5, Organic Matter Amendments, discusses the types of organic matter available, how to determine rates, and how it is applied. On some sites where the topsoil has been removed, pH levels will need to be raised to improve plant growth. Section 10.1.6, Lime Amendments, details the methods for determining liming rates, materials, and application methods. Many sites devoid of topsoil will require the introduction of mycorrhizae or nitrogen fixing plants. Section 10.1.7, Beneficial Soil Microorganisms, covers how to obtain and apply the appropriate sources of these important biological organisms. Revegetation projects can be enhanced by integrating plants into bioengineering structures, water capture features, or planting islands or pockets. These are discussed in Section 10.1.8, Topographic Enhancements.

10.1.1 FERTILIZERS

10.1.1.1 Introduction

Fertilizers are used to bring soil nutrients up to levels essential for establishing and maintaining a desired plant community. When applied within a soil fertility strategy, using fertilizer can be a great tool for revegetation. In recent years, however, the use of fertilizers on roadsides has come under greater public scrutiny and more restrictive water quality laws. Many roads are adjacent to streams, lakes, or residential areas which can be affected by runoff or leaching of inappropriately applied fertilizers. It is important for the revegetation specialist to learn how to develop fertilizer prescriptions that integrate short- and long-term site fertility goals with water quality objectives.

Use of commercial fertilizer is only one of many options to increase nutrient levels. A soil fertility strategy should also consider the application of topsoil, mulch, compost, wood waste, biosolids, and/or the planting of nitrogen-fixing species. This section will guide the revegetation specialist through the steps necessary to develop a site specific fertilizer prescription. The process for developing a fertilizer prescription follows these steps:

- Determine nutrient thresholds and deficits,
- Delineate areas to be fertilized,
- Select fertilizer analysis,
- Select fertilizer release rates,
- Determine application rates,
- Determine timing and frequency, and
- Select application method.

The fertilizer prescription is the basic instructions for ordering and applying fertilizers.

10.1.1.2 Develop Nutrient Thresholds and Determine Deficits

All sites have a minimum, or threshold, level of nutrients that must be met for each plant community to become functioning and self-sustaining (See Section 5.5). Threshold values can

***Figure 10.1** – Threshold values are determined from reference sites. In this example, the threshold was established at 1,100 lb/ac, which was between the total N of a disturbed reference site with "poor" revegetation (A) and one with "fair" revegetation (B). Total N in post-construction soils was 650 lb/ac (C), making these soils deficient by 450 lb/ac. The undisturbed topsoil of reference sites showed a total N of 2,430 lb/ac (D), which sets the target levels of nitrogen between 1,100 and 2,430 lb/ac.*

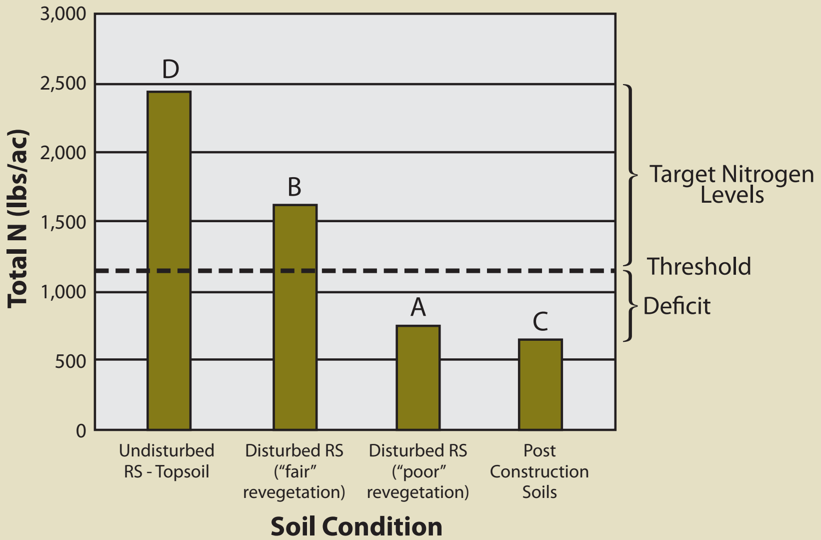


Figure 10.2 *– Determining the amount of nitrogen (N) needed to bring soils up to a nitrogen threshold can be calculated from equations shown in this spreadsheet.*

A	Total soil nitrogen (N)	0.025	%	From soil test of post construction soils – gr/l, ppm, mg/kg, ug/g divide by 10,000 for %
B	Thickness of soil layer	0.5	feet	The thickness of soil represented in (A)
C	Soil bulk density	1.4	gr/cc	Unless known, use 1.5 for compacted subsoils, 1.3 for undisturbed soils, 0.9 for light soils such as pumice
D	Fine soil fraction	70	%	100% minus the rock fragment content – from estimates made from sieved soil prior to sending to lab
E	N in soil layer: A * B * C * D * 270 =	331	lbs/ac	Calculated amount of total nitrogen in soil layer To convert to kg/ha: E * 1.12
F	Minimum or threshold N levels	1,100	lbs/ac	Determined from reference sites (see Figure 10.1)
G	N deficit: F - E =	769	lbs/ac	Minimum amount of N to apply to bring up to threshold

be determined by comparing soil tests from several disturbed and undisturbed reference sites (See Chapter 4). Disturbed reference sites should range from poor success to good. Based on nutrient values from good and poor revegetation sites, a target can be estimated between these values. Figure 10.1 gives an example of how a nitrogen threshold value was obtained by evaluating the total soil nitrogen levels from two disturbed reference sites, one considered "fair" revegetation and one considered "poor." The threshold was set between these two nitrogen levels. Threshold levels represent the minimum level of nutrients needed for a site. However, higher nutrient levels are more desirable. In fact, the target nitrogen levels in this example for establishing and maintaining the original plant community would be closer to the undisturbed reference site.

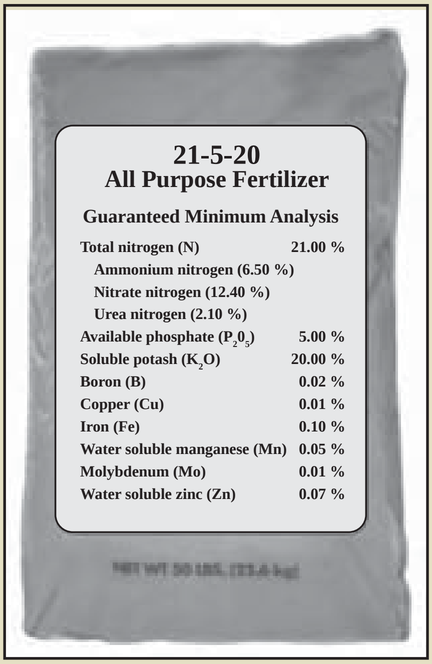
To determine whether any nutrient is deficient, post-construction soils must be collected and tested. The values obtained from these tests are compared against target values to determine if a deficiency exists. By comparing post-construction nutrient values against threshold values, the nutrient deficit can be estimated for each nutrient. Figure 10.2 shows an example of how nitrogen deficits are calculated based on post-construction soil tests and established threshold levels. In this example, total soil nitrogen is determined from soil tests. Since soil testing facilities report nutrients in a variety of rates, it is important to convert the rates to percentages. This is done by dividing values that come as gr/l, ppm, mg/kg, and ug/g by 10,000 to convert to a percentage. Converting percentage of nutrient in the lab sample to lb/ac of the nutrient requires multiplying % of nutrient, soil layer thickness, soil bulk density, and fine soil fraction together with a constant (line D). This is the pounds of nutrient in an acre of soil on the post-construction site. To determine the nutrient deficit, the pounds of nutrients per acre is subtracted from the threshold level. This value becomes the basis for determining fertilizer prescriptions.

The availability of many nutrients is regulated by soil pH. As discussed in Section 5.5.5, many nutrients are tied up in low pH and high pH soils. Calcium and magnesium are less available at low pH; phosphorus, iron, manganese, boron, zinc and copper become unavailable in high pH soils. It is important to compare the pH of post-construction soils with reference site soils to determine if the pH is substantially different between the two. If the pH of post-construction soils is different, then taking measures to bring the pH closer to pre-disturbance values should be considered when developing a nutrient strategy (See Sections 5.5.5.3, 5.5.5.4, 10.1.5, and 10.1.6).

10.1.1.3 Delineate Areas to be Fertilized

The post-construction project site should be delineated by distinct areas where fertilizer prescriptions differ. These differences are usually based on post-construction soil type changes, topsoil salvage, organic amendment additions, or the species and plant material being grown. Areas adjacent to, or that feed into, live water are often delineated and treated with lower rates of fertilizer. Note: If seedlings of shrubs and trees are being planted, spot fertilization should be considered in addition to, or in lieu of, fertilizing the entire area (See Inset 10.1, Spot-Fertilizing Seedlings).

__Figure 10.3 –__ An example of a fertilizer label for an "all purpose" fertilizer. The top numbers (in bold) represent the percentage of nitrogen, phosphorus, and potassium respectively (21%N, 5% P_2O_5, and 20% K_2O). Multiplying these percentages by the pounds of bulk fertilizer applied per acre will give the quantity of each nutrient applied per acre. In this analysis, 500 pounds of fertilizer in this analysis would deliver 105 lbs N, 25 lbs P_2O_5, 100 lb K_2O, 0.1 lbs B, 0.05 lbs Cu, and so on.



10.1.1.4 Select Fertilizer Analysis

There are a variety of commercially available fertilizers that can be used for fertilizing disturbed sites associated with road construction. The composition, or makeup, of the fertilizer is called the fertilizer analysis. Each container of fertilizer will have a label with a stated "guaranteed analysis" that indicates the percentage of each nutrient contained in the fertilizer (Figure 10.3). The label is your guide for determining which fertilizers to select and how much to apply. Tables 10.1 and 10.2 give analysis values for many common fertilizers. Labels can also be obtained from the manufacturer or fertilizer representatives.

The fertilizer label reports the nutrients as a percentage. The example label for a 50 lb bag of fertilizer in Figure 10.3 shows 21% nitrogen (N), which indicates that 10.5 lb of material in the bag is made up of nitrogen (50 * 21/100=10.5). The bag also contains 0.02 % boron (B), which indicates that there is 0.01 lb boron in the bag. Calculating the amount of phosphorous and potassium in the bag is a little trickier because the convention for reporting these nutrients is P_2O_5 and K_2O instead of elemental P and K. To convert P_2O_5 to P, the analysis for P is divided by 2.29. The percentage of P in the bag in Figure 10.3 is actually 2.2%, not 5% (5.0%/2.29=2.2). K_2O is divided by 1.21 to obtain 1.6% K.

Fertilizers are selected based on whether they contain the nutrients that are deficient on the project site. For example, if nitrogen, phosphorus, and boron are deficient, only fertilizers that contain these nutrients need be considered. Most fertilizers contain more than one nutrient. For instance, ammonium sulfate contains nitrogen and sulfur; triple superphosphate contains phosphorus, sulfur and calcium. Organic fertilizers often contain a range of macro and micronutrients. Fertilizers containing more than one nutrient should be considered if the nutrients contained in these fertilizers are deficient in post-construction soils. Table 10.1 and Table 10.2 show the combination of nutrients that are available in some commercially available fertilizers.

Fertilizer selection should focus first on the macronutrients (nitrogen, potassium, and phosphorus) that are deficient. These three nutrients are considered most important for long-term site recovery. If they are not deficient, chances are that the remaining nutrients are not either. On most highly disturbed sites, nitrogen is most likely to be deficient. This nutrient should be considered first when approaching fertilizer selection. Table 10.2 lists common nitrogen fertilizers with typical label analysis. Nutrients other than nitrogen can be supplied by fertilizers shown in Table 10.1. It is common to apply more than one fertilizer to meet the various nutrient requirements of the soil.

10.1.1.5 Select Fertilizer Release Rates

Fertilizers are grouped by how quickly they break down and release nutrients to the soil. They are either fast-release or slow-release. Release rates are important because they will determine the rates at which nutrients become available to plants during the year. If nutrients are released during periods when vegetation cannot use them, some will be lost from the site through soil leaching. This is not only a waste of fertilizer, but can be source of ground water pollution.

***Fast-Release Fertilizers* –** Fast-release fertilizers are highly soluble fertilizer salts that dissolve rapidly and move quickly into the soil during rainstorms or snowmelt. The fertilizer label will give an indication of how quickly nutrients are released. Terms such as "soluble," "available," or "water soluble" indicate that these nutrients are released relatively quickly. "Ammonium" and "nitrate" forms of nitrogen are also indications of fast-release fertilizers. The fertilizer label shown in Figure 10.3 would indicate that this bag contains a fast-release fertilizer and most of the nitrogen would be relatively mobile and available to plant growth within the first growing season. Ammonium nitrate, ammonium sulfate, potassium nitrate, and urea are several examples of fast-release fertilizers.

Table 10.1 *– Analysis of some common fertilizers. Nitrogen fertilizers are shown in Table 10.2.*

		Available Nutrients (typical values)													
	Source	% N	% P_2O_5	% P	% K_2O	% K	% S	% Ca	% Cu	% Fe	% Mn	% Zn	% B	% Mo	% Mg
Phosphorus	Mono-ammonium phosphate	11	48	21			24								
	Ammonium phosphate	82													
	Diammonium phosphate	17	47	21				21							
	Single superphosphate	19					12	20							
	Triple superphosphate		45	20			1	13							
	Phosphoric acid		53	23											
	Dicalcium phosphate														
	Soluble potassium phosphate														
	Superphosphoric acid		80	35											
Potassium	Potassium chloride				61	50									
	Potassium nitrate	13			45	37									
	Potassium sulphate				51	42	18								
Micronutrients	EDTA								10	10	10	10			
	HEEDTA								6	7	7	9			
	NTA									8					
	DTPA									10					
	EDDHA									6					
	Granular borax												11.3		
	Copper sulfate								25						
	Ferrous sulfate									20					
	Sodium molybdate													40	
	Zinc sulfate											36			
	Zinc chelate											4			
Ca & Mg	Dolomitic limestone							21							11
	Magnesium sulfate														43
	Gypsum							23							
	Epsom salt (Epsogrow brand)						13								10

***Table 10.2** – This table gives estimated nitrogen release rates for some commercially available fertilizers. Most release rates were obtained from lab testing. How they actually release on-site will vary from site to site, depending on temperature, moisture, and whether the fertilizer was placed on the surface or incorporated into the soil. If slow-release fertilizers are broadcast on the soil surface, release rates should be slower than if incorporated into the soil where the conditions are better for break down. Arid sites should have slower rates of release than sites with high moisture; cold sites should take longer to release nutrients than warm sites. First year nitrogen release rates for fertilizers are identified with an asterisk were adapted from Claassen and Hogan (1998). Non-asterisk fertilizers were based on best guess estimates.*

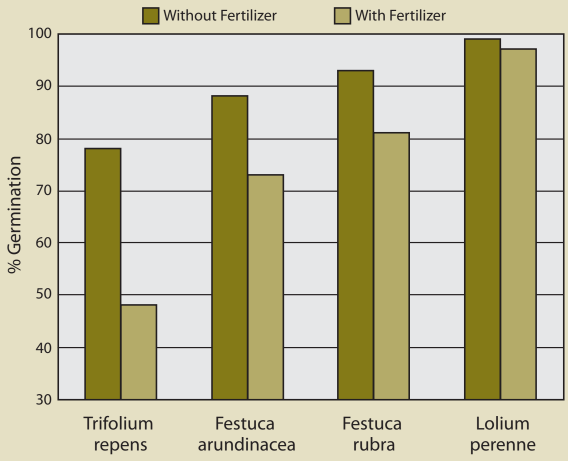
Source	Available Nutrients			
	N %	1st year N release (%)	% P_2O_5	% K_2O
Ammonium nitrate	34	99 to 100	0	0
Ammonium phosphate*	10	99 to 100	34	0
Ammonium sulfate	21	99 to 100	0	0
Anhydrous ammonia	82	99 to 100	0	0
Biosol® *	7	50 to 70	2	3
Calcium nitrate	15.5	99 to 100	0	0
Diammonium phosphate	18	99 to 100	46	0
Fertil-Fibers® *	6	50 to 70	4	1
Gro-Power® *	5	95 to 99	3	1
IBDU	29	95 to 99	3	10
Osmocote 18-6-12® *	18	95 to 99	16	12
Polyon PCU 40® *	30	99 to 100	0	0
Potassium nitrate	13	99 to 100	0	45
Ringer® *	5	50 to 70	10	5
Sustane® *	5	50 to 70	2	4
Urea	46	99 to 100	0	0

"Water soluble" or "available" nutrients do not always remain available or soluble after they are applied to the soil. Available forms of phosphorus, for instance, react in the soil to form less soluble compounds; potassium gets bound up in soils with moderate to high proportions of clay; and many of the micronutrients (e.g., zinc, copper, manganese) become unavailable when applied to soils with low pH (See Section 5.5.5). Unless soils are sandy or rocky, it can be assumed that many of the nutrients stated as "available," except for nitrogen and sulfur, will become somewhat immobile once they are applied. Over time, however, these nutrients will become available for plant uptake.

The advantages of fast-release fertilizers are they are relatively inexpensive, easy to handle, immediately available to the plant, and can be applied through a range of fertilizer spreading equipment. Disadvantages are that some nutrients, such as nitrogen, will leach through the soil profile if they are not first taken up by plants or captured by soil microorganisms in the break down of carbon. Nitrates from fast-release fertilizers have been found to leach through sandy soils to depths that are 4 times the rate of rainfall (Dancer 1975). For example, for sites with annual rainfalls of 12 inches, nitrate could move to a depth of four feet if it was not taken up by plants or soil organisms. At this depth, nitrogen would be out of range of most establishing root systems.

Since fast-release fertilizers are salts, they have a potential to burn foliage and roots, especially when fertilizers are applied at high concentrations or when applied during dry weather (See Section 5.5.5.2). High concentrations of fast-release fertilizers can also affect germination rates (Figure 10.4) because of the high soluble salt levels (Brooks and Blaser 1964; Carr and Ballard 1979). Salt damage can be reduced by mixing fast-release fertilizers at lower concentrations or by applying them during rainy weather.

Figure 10.4 – Germination of seeds for some species can be reduced following exposure to a 10-30-10 fertilizer solution at a rate of 750 lbs fertilizer per 1,000 gallon hydroseeder (after Carr and Ballard 1979).



Slow-Release Fertilizers – These fertilizers are designed to release nutrients at a much slower rate. To be labeled slow-release fertilizer, some states require a specific amount of nitrogen to be in a slow-release form. Forms of nitrogen shown on the label as "slowly-available" or "water-insoluble" are good indicators that a fertilizer is in a slow-release form. The advantages of using slow-release fertilizers are: 1) nutrients are supplied at a time when plants are potentially growing; 2) less frequent applications; 3) less potential for leaching into ground water; and 4) less potential to cause salt injury. The disadvantages are that many slow-release fertilizers are bulky, cost more to purchase and apply, and are limited by the type of fertilizer application equipment that can be used. On the whole, however, slow-release fertilizers have greater applicability for revegetating disturbed sites than fast-release fertilizers.

Slow-release fertilizers come in either organic or inorganic forms. Organic fertilizers include animal manures (including chicken, steer, cow), bone meal, fish emulsion, composted sewage sludge, and yard waste. Unprocessed organic fertilizers are hard to apply to roadside projects because they are bulky and high in moisture. Commercially available organic fertilizers, such as Fertil-Fiber™ and Biosol®, have been processed to remove most moisture, which makes them easier to apply through most fertilizer spreading equipment.

The agents responsible for release of nutrients from organic fertilizers are decomposing soil bacteria. When soil bacteria are active, the release of nutrients is high; when dormant, the rate is low. The release of nutrients is therefore a function of moisture and temperature, which governs the rate of bacterial growth. Warm temperatures and high moisture, conditions conducive to plant growth, are also favorable for the break down of organic fertilizers. Because of this, the release of nutrients from the decomposition of organic fertilizers often coincides with the period when plants are growing (spring and fall) and the need for nutrients is greatest. The nutrient release mechanism of slow-release organic fertilizers reduces the risk that highly mobile nutrients, such as nitrogen, will be released in the winter months when plants are incapable of absorbing them and the potential for leaching is greatest.

Inorganic forms of slow-release fertilizers were developed for the horticulture and landscape industries where they have become an effective method of fertilizing nursery plants. These are an expensive form of fertilizer and have not been tested on roadside revegetation conditions. Nevertheless, they should not be overlooked in their potential applicability for some native revegetation projects.

Inorganic slow-release fertilizers include ureaform, nitroform, IBDU (isobutylidene diurea), sulfur-coated urea, and polymer-coated nitrogen, phosphorus, and potassium. These fertilizers have varying mechanisms for nutrient release. Fertilizer granules coated with materials that release nutrients only during warm, moist conditions assure that nutrients are available during the period that plants are most likely to be growing. These coatings include sulfur (e.g., sulfur-coated urea) and polymers. Each fertilizer has its own formulated nutrient release rate, which varies from 3 months to 18 months. Release rates are available from the manufacturers for most inorganic, slow-release fertilizers. However, it should be noted that these rates were developed for 70 °F soil temperatures (Rose 2002), which are higher than soil temperatures in the western

***Figure 10.5** – An example of calculating fertilizer application rates to reduce nitrogen deficits.*

A	Nitrogen (N) deficit	769	lbs/ac	Calculated from example in Figure 10.2
B	N in fertilizer	8	%	From fertilizer label
C	Total bulk fertilizer needed: A * 100/B =	9,613	lbs/ac	To eliminate deficit
D	Est. first year N release rate of fertilizer	40	%	From Table 10.2 or obtain from manufacturers
E	Available N first year in fertilizer from 1st year application: B * C * D/10,000 =	308	lbs/ac	N available to plants and soil
F	Short-term N target (first year)	50	lbs/ac	Depends on C:N ratio, plant cover, and age (see text)
G	Excess nitrogen: E - F =	258	lbs/ac	Wasted N-could leach from soils into water
H	Adjusted rates of fertilizer to add: F * 100/D * 100/B =	1,563	lbs/ac	To assure that N released first year is not wasted
I	Remaining N deficit: A - (H * B/100) =	644	lbs/ac	Additional N needed as later applications of fertilizer

United States during the spring and fall when roots and foliage are growing. If roadside soils are colder than 70 °F, nutrient release will take longer than what the manufacturer states.

10.1.1.6 Determine Fertilizer Application Rates

Fertilizer rates are determined for each deficient nutrient as shown in Figure 10.5. The calculation in this example was done to eliminate a nitrogen deficit of 769 lb/ac. Using a slow-release fertilizer with 8% nitrogen, the amount of bulk fertilizer necessary to bring nitrogen levels to minimum targets is 9,613 lb/ac (769*100/8=9,613), which is an extremely high rate of fertilizer to apply. On the other hand, using a fast-release fertilizer with higher nitrogen analysis, such as ammonium nitrate (33% N), would reduce the amount of bulk fertilizer to 2,330 lb (769*100/33 = 2,330). While there would be less weight with this more concentrated fertilizer, this is considered a dangerous rate of fertilizer to apply. It would be risky and wasteful considering the potential for leaching high amounts of nitrate through soil into the ground water or the possibility of creating high salt levels toxic to plant growth. This example illustrates the difficulty in developing fertilizer prescriptions to meet long-term nutrient targets. How does the revegetation specialist develop a fertilizer strategy to meet short-term and long-term plant needs without over- or under-fertilizing?

The approach presented in this section is based on building long-term nutrient objectives around meeting short-term nutrient needs of the establishing plant community. For example, applying fertilizer at the time of sowing requires very low rates of available nitrogen to meet the first year needs of the establishing vegetation. Any extra fertilizer has the potential of being wasted. As the vegetation develops over the next few years, the ability of the plant community to take up more available nutrients increases and the fertilizer rates would be gradually increased. This practice, however, is seldom employed in roadside revegetation projects. In fact, the typical fertilizer practice does just the opposite – high rates of fertilizers are put on with seeds before there are even plants to utilize the available nutrients. In this practice, there is no return to the site in later years to assess whether additional applications of fertilizers might be essential for vegetation maintenance or growth. The approach we advocate is applying the appropriate mix of fertilizers to meet the annual needs of the vegetation while building long-term nutrient capital until the plant community is self-sustaining.

Since nitrogen is the key nutrient in establishing plant communities, this approach requires setting short-term and long-term nitrogen requirements of the plant community being established. Calculating long-term nitrogen targets is covered in Section 10.1.1.2. Short-term targets are more difficult to set because they change over time. They are governed by:

- Soil type,
- C:N,
- Climate,
- Amount of vegetative cover,

- Type of vegetation, and
- Age of vegetation.

Some general guides can be helpful in setting short-term nutrient targets for available nitrogen. Applying fertilizer at the time of sowing, for instance, will require very low rates of available nitrogen the first year since vegetation will not be established well enough to utilize it. Rates can be set below 25 lb/ac when applying fertilizer with seeds. When vegetation is becoming established, available N can range from 25 to 50 lb/ac (Munshower 1994: Claassen and Hogan 1998). After plant establishment, rates can be increased to account for increased plant utilization above this amount. These suggested rates should be adjusted upward on sites where high C:N soil amendments, such as shredded wood or straw, have been incorporated into the soil to compensate for nitrogen tie-up. Calculating precise rates of supplemental nitrogen for incorporated organic amendments is very difficult. In nursery settings, rates of over 100 lb of supplemental nitrogen have been recommended for incorporated straw, sawdust, and other high C:N materials (Rose and others 1995). However, applying supplemental rates in wildland settings should be done with caution, utilizing trials where possible to determine more precise fertilizer rates. Utilizing periodic soil analysis can give the revegetation specialist a better understanding of the soil nitrogen status. To keep testing costs low, only available nitrogen and total nitrogen need to be tested (See Section 5.5 for soil sampling and testing methods).

In determining how much fertilizer to apply, it is important to estimate how much nitrogen will be available the first year and the second year. Manufacturers have this information for most inorganic slow release fertilizers, and Claassen and Hogan (1998) performed tests on organic slow release fertilizers (shown in Figure 10.2). Release rate determinations are performed in the laboratory. How fertilizers actually release in the field will vary by the environment. In the example described in Figure 10.5, the first year release rate of nitrogen from the slow-release organic fertilizer was estimated at 40%. This was a guess based on the manufacturer's estimates of 55% release, but because it was being applied to a semi-arid site where decomposition of the fertilizer would be slow, the rate was dropped to 40% (Line D in 10.5). If 40% of the nitrogen became available the first year, 60% would remain for the following years (Line E). At this release rate, 308 lb/ac of nitrogen would become available the first year after application (Line F). While this is an extremely high rate, consider the application of ammonium nitrate at 100% first year release, which would supply 769 lb/ac (Line A) of immediately available nitrogen. Recalculating fertilizer rates using a more realistic rate of 50 lb/ac available nitrogen needed the first year after application (Line F), bulk fertilizer application rates would be 1,563 lb/ac (Line H). At this new rate, the site would have sufficient first- and second-year supplies of nitrogen, but lack adequate nitrogen the following years. The remaining deficit to meet long-term nitrogen targets would be approximately 644 lb/ac, which must be supplied through later applications of fertilizer or other carriers of nitrogen (topsoil, compost, biosolids, wood waste, mulch, and nitrogen-fixing plants). A nutrient strategy should be built around reducing nitrogen deficits over time.

The process outlined in Figure 10.5 can be used for other deficient nutrients. Understanding the availability of other nutrients is problematic. Many nutrients become fixed in the soils and their availability is dependent on highly variable factors such as soil texture, pH, and placement in the soil. It is a reasonable assumption that unless the soils are sandy or very rocky, that all nutrients, aside from nitrate or ammonium forms of nitrogen, are relatively unavailable the first year after application. With time, however, they will slowly become available.

10.1.1.7 Determine Timing and Frequency

The primary reason to fertilize is to supply nutrients during periods when plants can take them up for growth. The demand for nutrients changes throughout the year depending on the physiological state of each plant. In nursery settings, fertilizers are adjusted throughout the year at rates and formulations that correspond to the requirements of the plant. While we do not have that capability in wildland settings, we can use the fertilizers available to us more wisely by applying our understanding of how the assortment of fertilizers function in meeting the nutrient requirements of plant communities. At least two plant growth phases should be considered in the timing of fertilizer application – 1) seed germination, and plant establishment and 2) post plant establishment.

Seed Germination and Plant Establishment Phase – Traditionally, fast-release fertilizers have often been applied at high rates in the fall during the seed sowing operation. This practice is a quick and easy way to apply fertilizers. However, the timing can result in ineffective and wasteful use of fertilizers (Figure 10.6B) (Dancer 1975). In addition, application of fast-release fertilizers at this time can potentially pollute water sources. Slow-release fertilizers are more appropriate for seed sowing in the fall because much of the fertilizer should last through the winter, releasing nutrients in the spring (Figure 10.6D).

Perennial grasses and forbs do not require high levels of nitrogen for germination and early establishment (Reeder and Sabey 1987). In fact, elevated levels of available nitrogen can be a problem because it encourages the rapid establishment and growth of annual weed species over slower-growing perennial grass and forbs (McLendon and Redente 1992; Claassen and Marler 1998). Applying high rates of fertilizers during germination and early seedling establishment should be reconsidered in terms of how much fertilizer is actually needed in the establishment phase and how much will be available later for plant growth (See Section 10.1.1.6).

One strategy is to apply little or no fertilizer during sowing and wait until seeds have germinated and grown into small seedlings before fertilizers are applied (Figure 10.6C). This strategy assures that nutrients are available when the seedlings actually need them, not before. Fertilizers applied as slow-release form are preferred because they have less potential for causing salt damage when applied over emerging seedlings. Another strategy is to wait until the following fall (Figure 10.6E) or spring (Figure 10.6F) of the second year to fertilize.

Post-Establishment **–** Once vegetation is established (one or two years after sowing), fertilizers can be applied at higher rates with the assurance that nutrients will be taken up by the plants. Slow- and fast-release fertilizers can be combined to provide short- and long-term nutrient requirements (Figure 10.6 E and F). Spring applications of fast-release fertilizers are more effective than fall application because of the higher nutrient requirements of growing plants during that period (Figure 10.6F). Spring applications also have less risk of damaging vegetation through fertilizer salts because precipitation in the spring is typically frequent enough to wash fertilizers from the foliage. It is always prudent to check the conductivity of a fertilizer solution being applied over existing vegetation to avoid salt damage. A conductivity meter can be used to measure the conductivity of the solution (See Section 5.5.5). If rates exceed 3,500 mS/cm, then diluting the solution or applying the fertilizer during rainy weather is advised. Fall application of fertilizers should be done at lower rates and early enough for nutrients to be utilized by the growing vegetation. Fertilizer rates can be adjusted based on plant phenology or dormancy to minimize salt damage. Fertilizing dormant plants is also a possible way to minimize damage.

10.1.1.8 Select Fertilizer Application Method

Since nutrients have varying degrees of mobility (nitrogen is highly mobile; phosphorus and many micronutrients are relatively immobile), how fertilizers are applied will determine how accessible nutrients are to the root system. If nutrients are highly mobile, the easiest and least expensive method is to apply fertilizer to the soil surface, or broadcast, to allow rainfall or snowmelt to release and move nutrients into the soil. A more difficult, yet more effective application method for immobile nutrients is to incorporate, or mix, fertilizers into the soil surface so fertilizer granules are uniformly distributed within the soil and accessible by root systems.

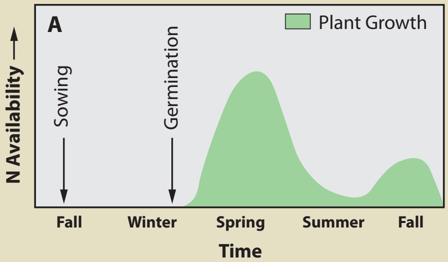
Broadcast Fertilizer Application **–** For fertilizers with highly mobile nutrients, such as nitrogen and sulfur, broadcast application on the soil surface is an appropriate practice. For immobile nutrients, broadcast fertilizer application can be relatively ineffective. These nutrients often become immobilized at the soil surface and are very slow to move into the rooting zone where they can be accessed. Depending on soil characteristics, such as pH and clay content, some immobile nutrients will take years to move only a few inches from the point of fertilizer placement.

There are a variety of dry fertilizer spreaders available, from hand-operated to tractor-mounted. Most equipment is limited to moderate slope gradients (less than 1V:2H). With all forms of spreaders, they must be calibrated before they are used to assure that the correct rates are being applied.

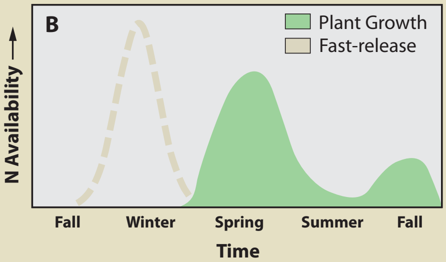
Hydroseeding equipment can be used to apply fertilizer in the same operation with seeds, tackifiers, and hydromulch (See Section 10.3.2, Hydroseeding). This equipment can also be used solely to apply fertilizers, especially after vegetation has become established. A great advantage to using hydroseeding equipment is that it can uniformly spread fertilizers on steep

Figure 10.6 – *Fertilizers should be applied during seasons, and at rates and formulations that release nutrients when native plants can efficiently draw them from the soil. The following are strategies for applying slow and fast release fertilizers.*

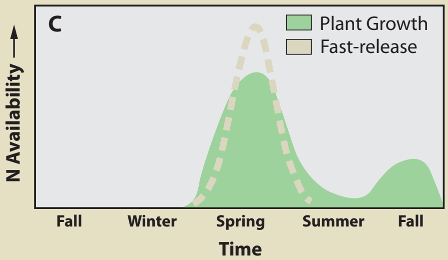
A. *When seeding occurs in the fall, seeds typically do not germinate until the following spring, at which time there is rapid growth. During the summer, growth rates slow. Growth rates accelerate again in the fall.*



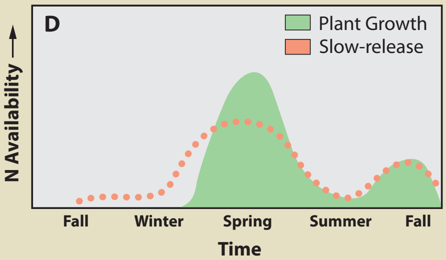
B. *When fast-release fertilizers (dashed line) are applied in the fall during seeding, fertilizers move into the soil with fall rains. However, there is no vegetation to take up the nutrients. Mobile nutrients, such as nitrogen, are leached and unavailable in the spring when the establishing plants require them.*



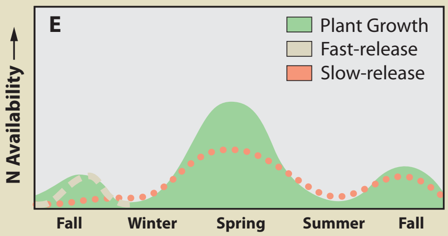
C. *Fast-release fertilizer applied in the spring after plants are established is more effective because plants are rapidly growing and can take up nutrients. There are fewer storms in the spring to leach nutrients from the soil.*



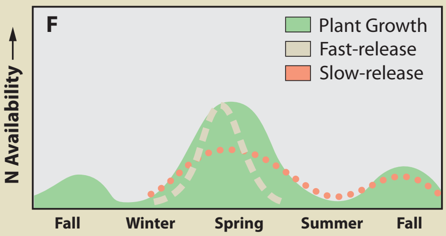
D. *Slow-release fertilizers (dotted line) release nutrients at a much slower rate. When they are applied in the fall, most of the nutrients should still be available in the following spring.*



E. *Once vegetation has become established, plant growth will take place in the fall. Fertilizers applied at this time will be taken up by growing vegetation. Since slow-release fertilizers might not be immediately available, small amounts of fast-release fertilizers can be added to give immediate release of nutrients.*



F. *Slow- and fast-release fertilizers can be applied in the early spring before rapid root and vegetative growth. Fast-release fertilizers can supplement slow-release fertilizers by supplying immediately available nutrients.*



Inset 10.1 – Spot-Fertilizing Seedlings

Fertilizing shrub or tree seedlings is done by placing fertilizer in each seedling hole or on the soil surface after each seedling has been planted. This practice has some risks, because fertilizers release salts which can damage roots. Studies have shown that placing fertilizers or liming materials in the planting hole or on the soil surface around seedlings at the time of planting can significantly decrease seedling survival, especially on droughty sites (Nursery Technical Cooperative 2004; Jacobs and others 2004; Walker 2002).

To reduce the likelihood of seedling damage, follow these practices:

- Assess the need for fertilizer (do not apply if nutrient levels are adequate).
- Use slow release fertilizers with low salt indexes.
- Use low rates of fertilizer if applying at the time of planting.
- If applying in seedling hole at planting, use low fertilizer rates and place fertilizer to the side at least 3 inches away from the root system.
- Preferably broadcast fertilizers on the soil surface after seedlings are well established.

When slow-release fertilizers are spread around well-established seedlings (several years after planting), seedlings often respond favorably, especially on highly disturbed sites. Walker (2005) showed that slow-release fertilizers broadcasted three years after seedlings were planted, increased stem diameter and shoot volume over the control seedlings by 143% and 104% respectively five years after the fertilizer was applied. In this study, rates of .05 grams of nitrogen per seedling showed the greatest response (at 8% nitrogen analysis, this would be over a half pound of bulk slow-release fertilizer per plant).

slopes and a variety of topographies. In addition, a combination of fertilizers can be easily mixed in the hydroseed tank and applied at relatively even proportions because they are in a solution. This is especially useful for applying small quantities of fertilizer, such as micronutrients, which are difficult to spread evenly over large areas.

Fertilizer Incorporation – It is important that nutrients that are deficient and have low mobility be incorporated into the soil prior to sowing or planting. Incorporation is possible on gentle slopes, but becomes very difficult with increasing slope gradients because of equipment limitations. On sites where fertilizers containing immobile nutrients cannot be incorporated, an alternative is to create roughened soil surfaces (See Section 10.1.2, Tillage) prior to fertilizer application. Broadcast fertilizers will accumulate in the depressions of the surface. As soil gradually moves into the depressions over time (through water erosion or surface ravel), the broadcast fertilizers will become covered with soil. When this happens, immobile nutrients are accessible by roots and nutrient uptake is possible. Surface roughening also reduces the potential for fertilizers to move off-slope through erosion.

Some agricultural spreaders, called fertilizer banders or injectors, are designed to place fertilizer, or other soil amendments including mycorrhizae, at varying depths in the soil. Usually this equipment has a ripping shank or tine that loosens the soil, followed by a tube that drops the fertilizer, and coulters or rollers that close up the furrow. As the bander is pulled through the soil, a line, or band, of fertilizer is created. Sowing and banding are often combined in one piece of equipment and applied at the same time. Fertilizer banders were developed for agricultural use and are limited by rock content and slope gradients. However, there are injectors that have been develop for wildland conditions (St John 1995).

The most common approach to incorporating fertilizer is accomplished in two operations, broadcasting fertilizer on the soil surface and tilling it into the soil. Hydroseeders and broadcast fertilizer spreaders, as discussed above, are means of applying the fertilizer evenly over the site, then the fertilizer is tilled into the soil using equipment outlined in Section 10.1.2, Tillage.

10.1.2 TILLAGE

10.1.2.1 Introduction

Tillage is defined in this section as any mechanical action applied to the soil for the purposes of long-term control of soil erosion and reestablishment of native plant communities. Tillage equipment was developed for agricultural soils and has limited applicability for steep, rocky sites typically encountered in wildland revegetation. This section will discuss the agricultural equipment that can be used for wildland revegetation as well as equipment specifically developed for these extreme conditions.

There are several reasons to use tillage in a revegetation project, including to:

- Shatter compacted soils,
- Incorporate soil amendments, and
- Roughen soil surfaces.

These objectives often overlap. For example, incorporating organic matter also loosens compacted soils and roughens soil surfaces. Identifying the objectives for the project will lead to selecting and effectively using the appropriate equipment to achieve the desired soil conditions (Table 10.3).

10.1.2.2 Shatter Compacted Soils

One of the primary purposes for tilling is to loosen compacted soils. When performed correctly, tillage can increase porosity in the rooting zone, increase infiltration rates, and increase surface roughness. For revegetation work associated with road construction and road obliteration, tillage to break up deep compaction is important for reestablishing plant communities. Shattering compaction at depths of at least 2 feet is essential for the healthy growth of most perennial plant species. Without this measure, it will take many decades for deep compaction to recover its original bulk density (Wert and Thomas 1981; Froehlich and others 1983). In a review of tillage projects on rangeland soils, Gifford (1975) found that deep tillage greatly reduced runoff, while shallow tillage had little effect.

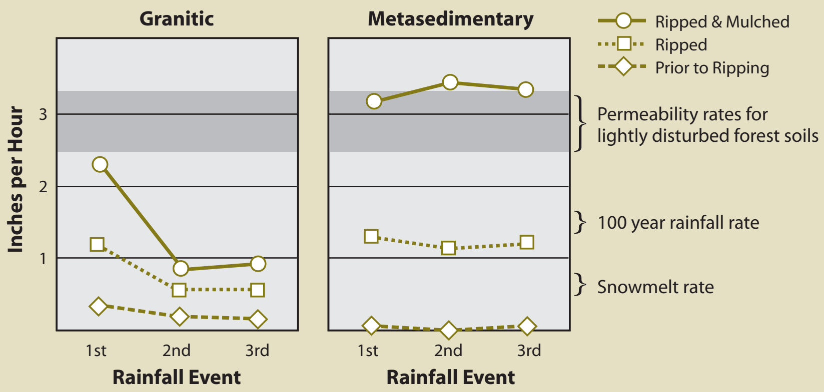
Tillage alone will not return a soil to its original bulk density or hydrologic function (Figure 10.7), nor will the effects of tillage last indefinitely, especially in non-cohesive soils (Onstad and others 1984). There are many factors that affect the return to bulk densities and infiltration rates typical of undisturbed reference sites. These include the type of tillage equipment used, penetration depth, soil moisture during tillage, soil texture, presence of topsoil, and organic matter content.

There are two fundamentally different equipment designs for reducing compaction. One design simply lifts and drops soil in place, shattering compacted soil in the process. This type of equipment includes rock rippers, subsoilers, and "winged" subsoilers. The second design churns and mixes the soil. Equipment that falls into this category includes disk harrows, plows, spaders, and attachments to excavators. This type of equipment can also incorporate soil amendments, like organic matter or fertilizers, in the same operation, and will be discussed in Section 10.1.2.3.

Table 10.3 *– The appropriate tillage equipment for the project depends on project objectives.*

	TYPE OF TILLAGE		
	Shattering	**Mixing**	**Imprinting**
OBJECTIVES	**Rippers & subsoilers**	**Disks, plows, excavator attachments**	**Dixon imprinter, excavator attachments, trackwalking**
Loosen compacted soil	Good	Good	Poor
Incorporate amendments	Poor	Good	Poor
Roughen surface	Good	Good	Good

Figure 10.7 – Short-term benefits of ripping (using a winged subsoiler) and mulching road surfaces vary by soil type, as shown in rainfall simulation tests on sites in northern Idaho. Granitic soils responded to ripping and mulching with increased permeability during the first storm, but permeability rates returned to near pre-treatments rates with successive rainfall events. Metamorphic soils reacted positively to both treatments and maintained high permeability rates after three rainfall events. Mulching improved permeability in both soil types. In fact, for metamorphic soils, the combination of ripping and mulching increased permeability to rates that were typical of lightly disturbed forest soils (adapted from Luce 1997).



The terms subsoiling and ripping are used interchangeably to describe soil shattering operations. Soil shattering involves pulling one tooth, or a set of teeth, at various depths through the soil to break up compaction created by equipment traffic. The rock ripper is a common tool found on most construction sites. When used to break up compaction, one or two large ripper tines are typically pulled behind a large bulldozer at 1 to 3 ft soil depths. While this equipment will break up compaction in portions of the soil where the ripper tines have been dragged, it does not effectively fracture the compacted soil between the ripper tine paths (Andrus and Froehlich 1983). The effectiveness of rippers can be increased by multiple passes through the soil or by adding tines to the toolbar. Even on small machines, up to 5 tines can be added to increase soil shatter.

Rippers have also been adapted to increase soil lift between tine paths by welding wide metal wings to the bottom of each tine. These wings are angled upwards so the soil between the tines has greater lift, and therefore greater shatter when the soil drops behind the wing. When two or more tines are placed together on a toolbar, they work in tandem to more effectively break up compaction. The resulting equipment is called the "winged" subsoiler (Figure 10.8). Andrus and Froehlich (1983) found that the winged subsoiler was a far more effective tool for breaking up compaction. This equipment fractured over 80% of the compaction in several operational tests, as compared to 18% to 43% for rock rippers and 38% for brush rakes. However, winged subsoilers are not practical in all soils, especially those with high rock fragments, buried wood, or slopes greater than 3H:1V gradients.

Figure 10.8 – Soil shattering becomes more effective when wings are mounted on subsoil tines. This equipment is called a winged subsoiler. Photo courtesy Brent Roath.

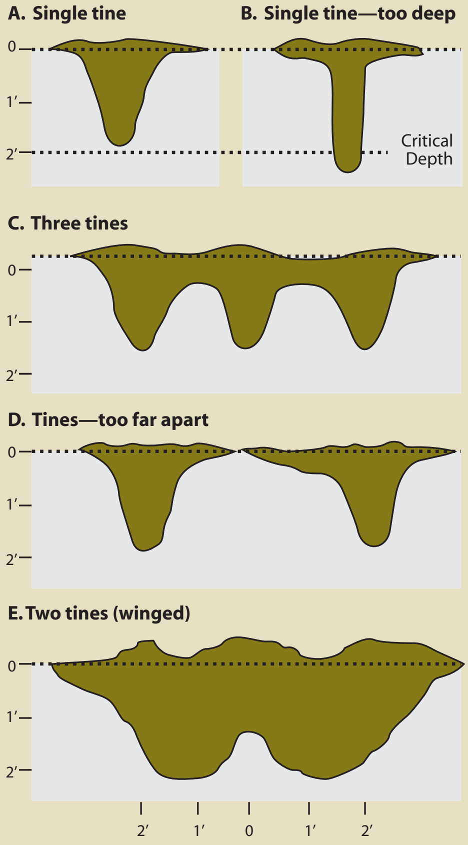
Achieving good shatter at deeper soil depths requires that tillage equipment be adjusted for site-specific soil conditions, especially soil texture, soil moisture, and large rock content. Soils should not be too moist during ripping because the tines will slice through the soil, causing very little soil shatter. Subsoiling when soils are extremely dry can bring up large blocks of soils, especially when the soils are high in clays (cohesive soils).

The winged subsoiler and rock ripper should be adjusted to meet the soil conditions of the site. Making the proper adjustments can lead to greater shatter and more efficient use of tractor equipment. These adjustments include:

- Tine depth,
- Tine spacing,
- Number of tines, and
- Wing width and angle (for winged subsoiler).

Tines should be set above the critical depth for the condition of the soil. If tines are set below this depth, the tines will not shatter the soil (Figure 10.9B). The critical depth changes for soil type and tine configuration. Soils high in clays with high soil moisture have shallower critical depths (Andrus and Froehlich 1983). The closer the spacing of tines, the greater the shattering. The more tines that are placed on a toolbar, the more area of soil can be shattered. However, where large rocks or large slash are present, closely spaced tines will drag these materials out of the ground. Three to five tines are typically used for most soil types. Wing size, angle, and shape of the tines all play a role in breaking up compaction (See Inset 10.2 for specifications for winged subsoiler).

***Figure 10.9 –** The effectiveness of subsoiling or ripping equipment to shatter compacted soil is a function of tine depth, number of tines, distance between tines, and wing configuration. Pulling a single tine (A) above a critical depth does some soil shattering as compared to a single tine ripping deeper than a critical depth (B). Placing 3 or more tines together (C) can be more effective than one tine, but tine spacing should not be too far apart or soils between the tines will not be shattered (D). Attaching wings to the tines is very effective in shattering compaction between the tines (E) (modified after Andrus and Froehlich 1983).*



Typical settings for rock ripper and winged subsoiler equipment configurations are shown in Table 10.4. These are suggested settings and should not be applied without first monitoring the results of the equipment on the project soils. The most direct method for monitoring soil shatter is to measure the depth to the compacted soil with a soil penetrometer or shovel (See Section 5.3.3.1). Immediately after a pass is made with the tillage equipment, the penetrometer is pushed into the soil and the depth to the compacted layer is recorded. Measurements are taken every 6 inches across a small transect perpendicular to the direction of the tractor and spanning the width of the tillage disturbance. Plotting the depths to compaction on graph paper gives a cross-section of the shattering pattern (Figure 10.9 is an example of plotting soil shatter). If the shattering pattern is inadequate, adjustments can be made to the tine depth, tine spacing, and angle of the wing. If these adjustments fail to increase soil shatter, a second and even third pass by the ripper or winged subsoiler should be

Table 10.4 – Recommended design features for some tillage equipment (modified after Andrus and Froehlich 1983; Froehlich and Miles 1984).

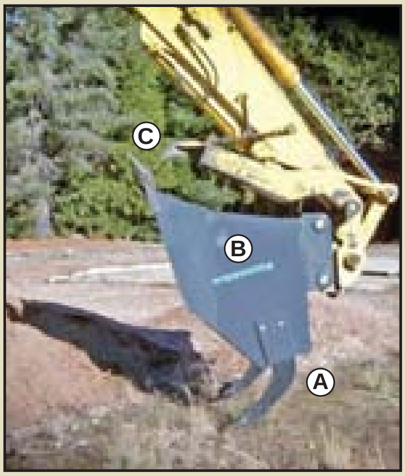
Item	Implement Feature	Recommended Design
Disk harrow	Disk diameter	40 - 50 in.
	Number of disks	6 -12
	Average disk weight	>1,800 lbs
	Disk arrangement	Offset gangs, independent disks
	Max slope (cross slope travel)	<5:1 H:V
	Max slope (down slope travel)	5:1 H:V
Brush blade	Tine spacing	22 - 26 in.
	Tine depth	<20 in.
	Max slope (cross slope travel)	>5:1 H:V
	Max slope (down slope travel)	3:1 H:V
Rock rippers	Tine spacing	24 - 30 in. (one pass)
		40 - 48 in. (two passes)
	Ripping depth	20 -24 in.
	Number of tines	5 (one pass)
		3 (two pass)
	Max slope (cross slope travel)	<5:1 H:V
	Max slope (down slope travel)	2.5:1 H:V
Wings of sub-soilers	Ripping depth	18 - 22 in.
	Number of tines	3 - 4
	Tine spacing	30 - 40 in.
	Wing width	12 - 24 in.
	Wing angle	10 - 60°
	Max slope (cross slope travel)	<5:1 H:V
	Max slope (down slope travel)	2.5:1 H:V

considered. Successive passes should be made at 45 to 90° angles from the first pass to achieve the greatest benefit.

A general rule for tillage work is to operate equipment on the contour to reduce the potential of water concentrating in the paths of the furrows and creating soil erosion problems. Operating equipment on the contour (cross slope) is limited to gentler slopes (Table 10.4). To optimize the use of equipment on steep slopes, down-slope operation of equipment must not create long, continuous furrows. It is also important to consider that if cuts and fills are left less compacted, there will be deeper rills and gullies created if concentrated flows of water are directed onto these slopes. These features are unsightly and can deliver high quantities of sediment to watercourses. Therefore, on slopes that have been tilled, it is important to redirect any concentrated flow of water that might enter the top of the cut to areas that are designed to handle this water. While it is not the job of the revegetation specialist to walk the tops of cuts and fills to determine whether concentrated water might flow into areas that are not designed for it, the success of the tillage project might depend on it.

Most soil shattering equipment is attached to a tractor toolbar and is limited to slope gradients of 3H:1V or less. Subsoilers and rippers are best used for projects that consist of gentle terrain or obliterated road sections. Newer equipment, such as the subsoiling grapple rake, has been developed to overcome these limitations. Attached to the arm of an excavator, this equipment can reach 35 feet up and down slope and specifically rip targeted areas of compacted soil (Figure 10.10).

***Figure 10.10** – The subsoiling grapple rake is a quick-mounting attachment to excavating machinery that combines several operations in one: (A) subsoiling with winged tines, (B) soil incorporation with bucket, and (C) removal of rock and slash with grapples (Photo courtesy of Mike Karr, Umpqua National Forest).*



10.1.2.3 Incorporate Soil Amendments

Tilling is used to incorporate fertilizers, organic matter, lime, and other amendments evenly throughout the soil, while loosening compacted soils. Tilling with these objectives requires equipment that mixes soil, such as plows, tillers, disks, chisels, and soil spaders. This equipment is tractor-drawn and limited to gentle slope gradients (5H:1V or greater) and soils low in rock fragments. These tools are not designed to break up deep compaction. Under most disturbed soil conditions, the best that can be expected this equipment is tillage to a depth of 8 to 12 inches.

Rippers and subsoilers are not very effective in incorporating materials such as fertilizers or organic matter into the soil. Nevertheless, spreading mulch on the soil surface prior to ripping or subsoiling usually incorporates enough organic matter into the soil surface to enhance infiltration rates (Luce 1997). In the same manner, fertilizers applied to the soil surface, especially those containing immobile nutrients, will be mixed into the top several inches of soil and made available to surface roots. On projects where topsoil has been salvaged and reapplied, subsoilers or rippers are the preferred equipment. Using equipment that mixes soils runs the risk of incorporating salvaged topsoil with the infertile subsoil.

A more recent set of specialized revegetation tools that mix and incorporate amendments have been developed for the tracked excavator. The arm of the excavator can reach 35 to 40 feet on steep cut and fill slopes and work soils that were previously inaccessible to most equipment. The simplest excavator attachment is the bucket which can be used to move topsoil or organic matter to concentrated locations and creating mounds or planting islands (See Section 10.1.8). When islands are created for deep-rooted species, such as shrubs and trees, soil can be excavated several feet deep with the excavator bucket and incorporated with organic matter amendments to create a deep rooting profile.

The subsoiler grapple rake (Figure 10.10) adds several design features to the excavator bucket. In addition to mixing organic amendments into the soil, the subsoiler grapple rake can remove large rock with the grapples and loosen soils with the winged subsoiling tines.

Inset 10.2 – Contract Specifications for a Winged Subsoiler

A winged subsoiler consists of a self-drafting, winged subsoiler on a dolly mount, sized for use with a D-7 tractor. The unit consists of three winged ripper tines capable of extending 12 to 34 inches below the draw bar. Wings shall be at least 20 inches wide with a 2 inch lift of the wings from horizontal. Tines shall have an individual tripping mechanism that automatically resets; tine spacing must be adjustable and individual tines must be removable. Various wing patterns must be available and easily interchangeable. Implement must be capable of achieving maximum fracture of compacted soils (minimum 24 inches) in one pass (Adapted from Wenatchee National Forest contract specifications).

10.1.2.4 Roughen Soil Surfaces

Tilling is often done to roughen the soil surface for erosion control and to create a more optimum seedbed (See Section 5.6.7). The micro-topography of a roughened surface consists of discontinuous ridges and valleys. The valleys become the catch basins for seeds and surface runoff. Seeds have greater opportunities to germinate and become established in the micro-valleys because of increased moisture, higher humidity, protection from the wind, and shelter from the sun. Surface roughening is a side benefit of the mixing and shattering operations discussed above in Section 10.1.2.2 and Section 10.1.2.3. Roughening is also accomplished by either scarifying or imprinting operations.

Scarification is the shallow loosening of the soil surface using brush blades, harrows, chains, disks, and chisels. Because it only loosens the soil surface several inches, the benefits for revegetation are only seen during seed germination and early seedling establishment. Once root systems hit the hard compacted layer several inches below the loosened surface, plant growth is curtailed.

Imprinting is a form of surface tillage that leaves the soil with a pattern of ridges and valleys. The equipment applies a downward compressive force to a metal mold, leaving an impression on the soil surface. The most basic type of imprinting is trackwalking (Figure 10.11). In this operation, tracked equipment are "walked" up and down cut and fill slopes, leaving a pattern of tractor cleat imprints on the soil surface no deeper than an inch or two deep. Imprinting methods that are tractor-based are restricted by slope gradients. Since heavy equipment is used, trackwalking can compact soils. Compaction is not often considered when selecting trackwalking practices because soils of most construction sites are already very compacted, and trackwalking is unlikely to significantly increase compaction. This is one reason why trackwalking has been considered beneficial for erosion control and revegetation because it does create a somewhat better "short-term" growing environment and reduces surface erosion and sedimentation on a very poor site.

An alternative to trackwalking is the use of the bucket of an excavator to pack and imprint the soil surface. Different patterns of steel "teeth" can be welded on the face of the bucket to achieve the desired surface micro-relief. Figure 10.12 shows a makeshift imprinter, which is simply 4 strips of angle iron welded to a bucket to create a pattern of 3-inch deep impressions. The excavator in this example can move topsoil in place, shape the cut and fill slopes, and imprint the surface, all with one operation.

If the last operation on a construction site is to subsoil or rip soils 1.5 to 2 ft deep and leave the soil surface in a roughened condition prior to revegetation, trackwalking would be more detrimental than beneficial on most soils. The tractor used to create imprints would compact the tilled soil leaving the surface smoother (less rough) than if left alone. If one of the construction objectives is to leave the construction soils in non-compacted condition,

***Figure 10.11** – Trackwalking creates imprints on the soil surface, but will also compact surface and subsurface soils.*

***Figure 10.12** – An alternative form of imprinting road cuts and fills that does not compact soils is welding angle iron onto the bucket of an excavator. As the excavator pulls topsoil into place and contours the slope, it presses the face of the bucket into the soil surface to form surface imprints.*

the use of trackwalking should be seriously weighed against the long-term impacts to plant establishment and growth. Compaction will affect surface infiltration and runoff, therefore, trackwalking should be critically evaluated for its potential increase in soil erosion. Rainfall simulation tests can be run on sites near the construction project that have been trackwalked and compared with those that have been left in an uncompacted state to determine the effects on runoff and soil erosion (Hogan and others 2007).

Specialized imprinters have been developed for rangeland restoration. For example, the "Dixon" imprinter was developed to restore perennial grasses for rangelands in Arizona and other arid states. It consists of a roller with large conical metal "teeth" that is pulled behind a tractor. The imprinter creates a pattern of V-shaped troughs, 4 to 7 inches deep, encompassing approximately 1 ft^2 area (Dixon and Carr 2001a, 2001b). These imprints are substantially larger and deeper than those created by trackwalking, with greater longevity. This equipment also has a set of ripping shanks attached to the tractor that shatters deeper compaction before imprinting.

10.1.3 MULCHES

10.1.3.1 Introduction

Mulch is defined as a protective material placed on the soil surface to prevent evaporation, moderate surface temperatures, prevent weed establishment, enrich the soil, and reduce erosion. Mulches therefore have many functions or roles in the recovery of native vegetation to a disturbed site. But confusion often arises around the use of mulches on revegetation projects unless the reasons for using them in a project are clearly defined. In this discussion, we have grouped mulches into four uses based on revegetation objectives:

- Seed Covering,
- Seedling Mulch,
- Soil Improvement, and
- Seed Supply.

For most projects, mulches are used to meet more than one objective. Problems arise when the methods for applying overlapping objectives are not compatible. For example, erosion control objectives and seed covering objectives go hand-in-hand because the soil surface needs to be stable for seeds to germinate and grow into young seedlings. In turn, the surface ultimately becomes stable through the establishment of young plants. Yet erosion control products and practices that are effective for controlling surface erosion are not always optimal for establishing vegetation. For this reason, it is important to understand the objectives for mulching and to integrate them into a comprehensive strategy when selecting mulch types and application methods.

This section discusses the objectives for applying mulches and the potential mulch sources. We have left the discussion of the effectiveness of mulches for erosion control and surface stabilization to the many publications and research devoted to this topic and focus primarily on the characteristics of mulches for plant establishment.

10.1.3.2 Seed Covering

One of the principal reasons for applying mulch is to enhance seed germination and early seedling establishment. During this critical period, desirable mulches will:

- Protect seeds and young seedlings from soil splash, sheet erosion, and freeze-thaw;
- Keep seeds moist during germination;
- Moderate surface temperatures during germination;
- Keep young seedlings from drying out; and
- Prevent salts from wicking to the surface and harming newly germinating seedlings.

The characteristics of mulch materials that make ideal seed coverings are those that protect seeds from drying winds, solar radiation, high evapotranspiration rates, and surface erosion while still allowing seeds to germinate and grow through the mulch into healthy seedlings. Long-fibered mulches, such as straw, wood strands, pine needles, and ground or chipped wood, placed at the appropriate thickness, usually meet these characteristics. When applied correctly, the strands of long-fibered mulch loosely bridge on top of each other, much like "pick-up-sticks," forming large air spaces or pores (Figure 10.13). Large pores function much like the air spaces in building insulation by moderating extreme temperatures.

***Figure 10.13** – Long-fibered mulches, like wood strands shown below, create a good growing environment because seeds and seedlings are protected from excessive drying during germination and early seedling establishment. On sites where freeze-thaw is prevalent, long-fibered mulches can insulate the soil and protect emerging seedlings.*

Compared to short-fibered mulches, such hydromulch, long-fibered mulches can be applied at greater thicknesses, which help maintain surface soil moisture and higher humidity around germinating seeds and emerging seedlings. In addition, long-fibered mulches can mitigate the effects of frost heaving at the soil surface (Kay 1978), significantly reduce high surface temperatures (Slick and Curtis 1985), and allow sunlight penetration, which enhances seed germination and seedling establishment. Large pores created by long-fibered mulches also allow better gas exchange between the soil and atmosphere (Borland 1990).

Short-fibered mulches, on the other hand, have smaller pores and form denser seed covers. These materials are typically applied thinly (Figure 10.14), so they offer less insulation than long-fibered mulches and therefore have less value as a seed covering. Some researchers suggest that very fine textured mulches can actually increase surface evaporation by wicking moisture from the soil to the surface of the mulch (Slick and Curtis 1985; Borland 1990; Bainbridge and others 2001). Short-fibered mulches are effective as an erosion control cover, but are considered inferior to long-fibered mulches for germination and early seedling establishment (Kill and Foote 1971; Meyer and others 1971; Kay 1974, 1978, 1983; Racey and Raitanen 1983; Dyer 1984; Wolf and others 1984; Norland 2000).

***Figure 10.14** – Hydromulch with tackifier can stabilize the soil surface for up to a year, but does not necessarily create an optimum environment for germinating seeds. The short-fibered textures typically form a covering that is too thin to maintain moisture around the seeds during germination when the weather is dry. The hydromulch (dyed with a green tracer) shown in this picture is applied at approximately 1,500 lb/ac.*

Erosion mats can perform well as seed covers (See Section 10.1.3.8). These materials come in rolls or sheets, which are laid out on disturbed soils and anchored in place after seeds have been sown. They are composed of such materials as polypropylene, straw, coconut, hay, wood excelsior, and jute. Good characteristics of erosion mats for seed germination and early seedling growth are those with enough loft, or porosity, to create a micro-environment for seed germination while allowing some sunlight to penetrate to the surface of the soil (Figure 10.15).

On sites where vegetation is expected to take several years to establish (e.g., arid, high elevation sites), it is important to apply a mulch with a longevity of more than one year. Materials with greatest longevity are most long-fibered wood mulches, as well as erosion mats made from polypropylene. Straw, hay, and short-fibered wood products are less likely to be present after the first year.

Mulching for seed covering is critical on sites that have: 1) high evapotranspiration rates during germination, 2) unstable soil surfaces, 3) susceptibility to freeze-thaw, and 4) high soil pH. It is less important on sites where soil surfaces do not dry out during seed germination or on projects where seeds have been covered by soil.

10.1.3.3 Seedling Mulch

Mulch is placed around newly planted or established plants to improve survival and growing conditions by:

- Reducing surface evaporation,
- Preventing the establishment of competing vegetation,
- Moderating surface temperatures, and
- Allowing water infiltration.

Studies have shown that survival and growth of young trees are significantly increased by applying mulches around seedlings at the time of planting (DeByle 1969; Lowenstein and Ptikin 1970; Davies 1988a, 1988b). Mulching around seedlings results in the greatest benefit on hot and dry sites (typically south and west aspects) and sites with aggressive competing vegetation. It is less important to mulch around seedlings on sites that have a low potential for establishing competing vegetation the first several years after planting. Mulching is also less critical on sites that have low evapotranspiration rates or high summer rainfall.

Seedling mulches are applied either as an organic aggregate or as sheets. Organic aggregate mulches consist of shredded or chipped wood derived from bark, wood, branches, sawdust, or lawn clippings applied deeply around seedlings. Sheet mulches are large pieces of non-permeable or slightly permeable materials made from translucent plastic, newspaper, or geotextiles (woven fabrics) that are anchored around planted seedlings (Figure 10.16).

Sheet Mulches **–** A variety of sheet mulches are available commercially. These mulches are popular because of the relative ease of transport and installation. The effectiveness of sheet mulches increases with the size of the sheets. For most hot, dry sites, a 2.5 by 2.5 ft sheet is considered to be the minimum dimension (Cleary and others 1988). On harsher sites, 3 by 3 ft or even 4 by 4 ft sheets are necessary to control competing vegetation. When purchasing and installing sheet mulches, the following should be considered (after Davies 1988a, 1988b):

1) **Select the right size.** The size of the mulch should be based on site conditions and the type and amount of competing vegetation. A hot, south-facing site with full cover of competing grasses will need a large sheet mulch; a north-facing slope with scattered forbs and grasses will suffice with the smallest size.

***Figure 10.15** – Erosion mats can be good seed covers. Mats with the highest loft create the best microenvironment for seed germination while allowing some sunlight to penetrate to the surface of the soil.*

***Figure 10.16** – Sheet mulches come in a variety of materials, such as the paper/ cardboard product shown in this picture. The size of the sheet mulch must be large enough to keep competing vegetation away from the seedling. The 3 by 3 ft sheet mulch shown around this Pacific madrone* (Arbutus menziesii*) seedling is the minimum size for this site.*

2) **Order only opaque materials.** Translucent materials should not be used as sheet mulches because weed seeds can germinate and grow under these materials. During the summer, surface temperatures under translucent materials can be lethal to seedling roots.

3) **Use sheet mulches with long life spans.** The durability of sheet mulch should be at least 3 years. It often takes 3 to 5 years for seedlings to become established on hot, dry sites (Cleary and others 1988).

4) **Weed or scalp around seedlings prior to installation.** Sheet mulch cannot be installed properly without competing vegetation being completely removed.

5) **Mulch immediately after planting.** Waiting until later in the spring to mulch runs the risk that competing vegetation will have depleted soil moisture, thereby making the mulch ineffective during the first growing season.

6) **Securely stake or anchor all corners of the mulch.** The sides of the mulch sheets can pull out easily by wind, animals, or competing vegetation growing under the mulch sheets. It is important that, at a minimum, the corners are staked. For greatest effectiveness, bury all edges of the sheets with soil.

7) **Consider visibility.** Sheet mulches can be very apparent in high visibility areas. Measures to reduce unsightliness of sheet mulches include covering with aggregate mulches such as hay, straw, or wood mulch, or selecting sheet mulch colors that blend into the area.

Figure 10.17 – *This photograph was taken in late summer, months after adjacent soils had dried out. The lack of competing vegetation and the low surface evaporation resulting from the placement of 3 to 4 inches of coarse sawdust resulted in very high soil moisture. The high C:N of the sawdust was believed to be a factor in inhibiting the establishment of weedy annuals.*

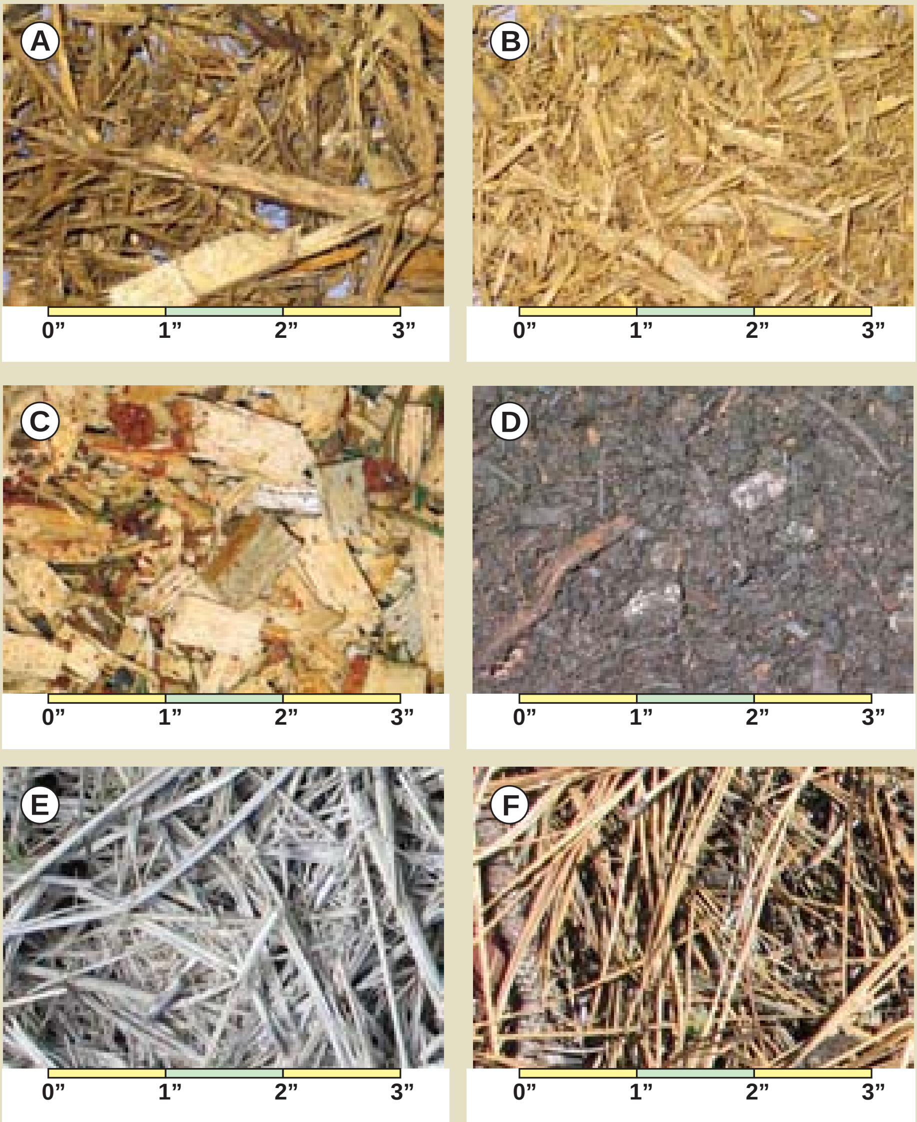
Organic Aggregate Mulch – Organic aggregates are another group of materials that, when placed thickly around installed plants, will control the establishment of competing vegetation and reduce surface evaporation (Figure 10.17). These aggregates include hay, straw, or chipped and shredded wood materials. Organic aggregates are often used in highly visible areas because they are more esthetic in appearance than sheet mulches. They are also used in planting islands for long-term control of competing vegetation.

The effectiveness of organic aggregate mulches on seedling survival and growth depends on the depth, total area covered, the control of seed germination of competing vegetation, and its longevity.

The longevity of organic aggregate mulches is a function of: 1) C:N, 2) texture, and 3) depth. High C:N materials, such as uncomposted, shredded wood, bark, or sawdust, will last longer than low C:N materials, such as composted yard materials, because these materials are in the initial stages of the decomposition cycle. Coarse-textured materials (Figure 10.18) have greater longevity than finer-textured materials because coarser materials have less surface area for microbial break down (Slick and Curtis 1985). Coarse-textured materials also tend to hold less moisture, which slows decomposition rates. The longevity of an organic aggregate mulch also depends on the application thickness – the thicker the layer of mulch, the longer it will last.

The same factors that affect longevity (e.g., texture, C:N, depth) also determine the effectiveness of aggregate mulches in deterring seed germination of unwanted vegetation around the seedling. Coarse-textured mulches are excellent mulches because they hold very little moisture at the mulch surface, and are therefore poor environments for seed germination of unwanted vegetation. Fine-textured mulches, on the other hand, create a more favorable environment for seed germination because they hold more moisture and are in closer contact with seeds. For this reason, many fine-textured materials, such as composts, are actually excellent growing media for weed seed germination and establishment. As discussed in Section 5.8.1.2, mulch materials with high C:N discourage growth of weedy annuals because high C:N materials remove available nitrogen that would otherwise give these species a competitive advantage. The effectiveness of a mulch in discouraging the establishment of competing vegetation generally increases with the thickness it is placed on the soil surface (Baskin and Baskin 1989). The most effective mulch thicknesses are between 3 to 4 inches (Pellett and Heleba 1995; Ozores-Hampton 1998), but thicknesses as low as 1.5 inches have been found to be effective for some small-seeded weed species that need sunlight for germination (Penny and Neal 2003).

***Figure 10.18** – Examples of different types and textures of mulches: (A) freshly ground coarse wood passing a 3 inch screen; (B) freshly ground coarse wood passing a 1.5 inch screen; (C) freshly chipped wood; (D) composted mixtures of ground wood, biosolids, and yard wastes passing a 1.5 inch screen; (E) weathered straw; (F) ponderosa pine needles.*



Organic aggregate mulches have several advantages over sheet mulches. First, organic mulches can be applied over a much larger area than sheet mulches. Some projects have organic mulches covering the entire site, while other projects concentrate it in strategic areas, such as planting islands. Second, organic aggregate mulches moderate surface soil temperatures, whereas sheet mulches can actually increase surface temperatures. Mulch thicknesses of 3 inches have been found to reduce soil temperatures below mulch layers by 8 to 10 °F (Slick and Curtis 1985; Steinfeld 2004), which can benefit the growth of seedlings on very hot sites. The insulative quality of mulches also affects the seasonal heating and cooling patterns in the soil. Soils under thick mulches take longer to warm in the spring, but in the fall, take longer to cool down. Depending on the temperature and rainfall patterns of a site, this could influence seedling establishment.

Mulch can create problems to planted seedlings if it is placed in contact with the plant stem. The high moisture around the stem can be conducive to pathogenic injury. On southern exposures, heat will build up at the surface of, and directly above, the mulch, creating extremely high temperatures on warm summer days. The high temperatures can cause heat damage to stems of young seedlings. It is important, therefore, to keep mulch several inches away from the stem of planted seedlings.

10.1.3.4 Soil Improvement

Mulches are sometimes used specifically to increase the nutrient and organic matter status of a soil. Composted organic materials are used for these purposes and are characterized by having low C:N, high nutrient levels, fine textures, and dark colors. While these materials are typically more effective when incorporated into the soil, they are sometimes applied to the surface of the soil where tillage is not feasible (steep and rocky) or tillage costs are unaffordable. Where composted organic materials are applied on the soil surface, the nutrient release rates will be much slower. See Section 10.1.5, Organic Matter Amendments, for more information on composts.

10.1.3.5 Seed Supply

The objectives for applying mulch on some projects are to spread materials that contain native seeds. There are several mulch materials that carry native seeds, including duff, litter, and straw from native seed production fields. When these materials are applied to the soil surface, seeds will germinate given favorable environmental conditions.

Duff and Litter **–** Duff and litter layers are organic mats that form under tree and shrub plant communities. These layers are accumulations of years of leaves and needles at varying degrees of decomposition. Included in these layers are dormant seeds, many of which are still viable. When the duff, litter, and seed bank is collected and spread on disturbed sites the environmental conditions for breaking seed dormancy of some species may be met and seeds will germinate.

Figure 10.19 – *Large mulching operations require access and working space. The operation shown in this photograph shows the wood waste material being dropped into a grinder with an excavator (left), and conveyed as mulch to the bucket of a front end loader (right).*

Duff and litter can be collected from adjacent forest- or shrub-dominated sites or salvaged prior to construction. Reapplying them to disturbed sites completes several operations at once: 1) adds seeds, 2) covers seeds, and 3) adds a supply of long-term nutrients. Although this practice might seem expensive or impractical, when compared with purchasing and applying seeds, fertilizer, and mulch separately, the costs might be comparable. See Section 10.1.3.11 for more information on litter and duff.

Native Hay From Seed Production Fields – One of the byproducts of native grass seed production is the stubble that remains in the fields after seed harvest. This stubble contains varying quantities of unharvested seeds, which eventually end up in bales. If bales are stored in dry conditions, seeds can remain viable for several years. When hay bales containing the native seeds are spread as a mulch on disturbed sites, seeds come into contact with soil and eventually germinate. See Section 10.1.3.9 for more information on straw and hay.

10.1.3.6 Selecting the Appropriate Mulch Materials

There are a variety of materials that can be used as mulches:

- Wood fiber,
- Erosion mats,
- Hay and straw,
- Manufactured wood strands,
- Duff and Litter,
- Composts (See Section 10.1.5), and
- Hydromulch (See Section 10.3.2).

The following sections describe these materials and how they are used in revegetation projects. Figure 10.18 gives examples of some of these mulches.

10.1.3.7 Wood Fiber

Mulches produced from woody materials are used primarily for seed covering and seedling mulching. There is usually a readily-available source of wood material from project sites situated in forested environments. Branches, stems, bark, and root wads are typical waste products from clearing and grubbing that can be chipped or mulched on site to produce various types of wood mulch. In the past, this material has been burned or hauled to waste areas for disposal. With greater burning restrictions and higher hauling costs, chipping these materials and returning them to disturbed sites as mulch are practices that are becoming more common.

Wood Fiber Mulch Production – Creating mulch from right-of-way clearing woody material requires planning and coordination. First the road contractor piles the woody right-of-way clearing debris into "slash piles." These piles include tree boles, bark, branches, and stumps, but must not contain large rocks or other inert materials that can cause wear or damage to the equipment. When clearing and piling is completed, a company that specializes in processing wood waste is contracted (typically by the road contractor). In this operation, equipment is brought to each slash pile and materials in these piles are processed into mulch. The resulting wood mulch is either placed in piles adjacent to the slash piles or transported to designated storage sites. The timing of these operations should consider the possibility of limited equipment use due to fire restrictions, which typically occurs in the western United States from mid summer through early fall.

If undesirable plant species are included in the slash piles, spread of these species is likely to occur when they are processed and applied as a mulch. This can be prevented by identifying these plant populations on site during the weed assessment (See Section 5.8.2.1) and avoiding placing them into slash piles.

It is important to define the desired mulch characteristics prior to processing the piles. This can be difficult since there are a variety of wood waste reduction equipment, producing different dimensions and fibrosity (the degree that wood fibers are separated). Specifying the particle size and shape by stating a screen size the material must pass does not always produce the desired material. Screens only sort for two dimensions, and not for length or fibrousness. Identifying the type of waste reduction equipment can narrow the type of mulch produced (Table 10.5). For example, mulch produced by shredders is long and fibrous (Figure 10.18 A and B), whereas

***Table 10.5** – Table of general types of wood waste reduction equipment (modified from Re-Sourcing Associates and CPM Consultants 1997).*

General Equipment Types	Examples	Feedstock	Particle Geometry
Chippers	Disc Chippers, Drum Chippers	whole logs, clean residuals	clean edge, two-sided
Hogs	Swing Hammer, Fixed Hammer, Punch & Die, Mass Rotor	wood waste, stumps, land clearing debris	coarse, multi-surfaced, fibrous
Shredders	Low Speed-High Torque, High Speed	wood waste, stumps, land clearing debris	coarse, multi-surfaced, fibrous
Hybrids	Knife Hogs, Pan & Disc	wood waste, stumps, land clearing debris	semi-coarse

mulch produced from chippers has close to equal length sides, with fibers still intact (Figure 10.18 C). Visiting with mulch company representatives and viewing the type of products they produce is a good way to determine the types of products you can expect to receive. If this is not possible, have them send you samples of different mulch products. Typically, the coarser the size of the mulch, the cheaper will be production costs since more mulch of coarser size can be produced in a given time frame than smaller textured mulch. Other factors, such as tree species, moisture content, and portion of tree processed, will affect the characteristics of the mulch. If the wood is wet during processing, it is more likely to be shredded; if it is dry, it will be more chip-like. There is also variation in mulches based on species of origin. For example, ponderosa pine (*Pinus ponderosa*) and western juniper (*Juniperus occidentalis*) tend to create more fibrous mulch than lodgepole pine (*Pinus contorta*). Processed root wads tend to be more fibrous than boles of trees.

Purchasing Wood Fiber Mulches – On projects where waste materials are not available for mulching, the purchase of wood fiber mulches should be considered. Overall costs are much higher because of the added expenses of transporting these materials to the site. If commercial mulch sources are nearby, this can be an economically viable option. It is very important to be sure of the quality of the material. Testing methods and specifications can be developed that are similar to those given in Section 10.1.5.

Applying Wood Fiber Mulch – Wood fiber mulch is typically applied with mulch-blowing equipment. This equipment has varying transport capacities, ranging from 25 to 100 yards of material (Figure 10.20). An application hose is positioned where mulch is to be applied and is pneumatically delivered from the mulch bins to the site. The amount of mulch applied depends on the objective. For seeding, application rates range from 100 yd^3/ac (0.75-inch thickness) to 135 yd^3/ac (1.0-inch thickness). For seedlings, mulch application ranges from 400 yd^3/ac (3 inch-thickness) to 540 yd^3/ac (4-inch thickness). Note: The higher rates used for mulching seedlings are only used in close proximity to the plants. The remaining areas are mulched at a lower rate.

Application rates depend on factors such as length and diameter of hose, blowing equipment, elevation rise, and dimension of the area being covered. Rates of application typically range from 25 to 35 yd^3/hr. If mulch is applied at a 1-inch depth (134 yd^3/ac), it would take between 4 to 5 hours to cover an acre. These are optimum rates because they do not account for the time it takes to travel to the mulch source, load the mulch bin, and travel back to the application site. The time required to make these trips can sometimes be longer than the actual application of the mulch. Using larger transport capacities is one way to significantly cut the time associated with refilling mulch bins.

Mulch blowing equipment can be used on any slope gradient that can be accessed by foot. By using ropes, slope gradients of up 1H:1V can be accessed. Hose lengths can be attached to extend the delivery of mulch up to 400 ft. Since mulch is delivered through hoses, the system will plug if the size of the wood fibers exceeds the tube size. It is therefore important that mulch be free of large pieces of wood. Using a mulch blower is an excellent method for evenly applying wood fiber, but frequent monitoring by inspectors is important to assure that the specified amount of mulch is being applied.

Where slopes gradients are gentle and free of rock and debris, wood fiber mulch can be evenly applied with a manure spreader. Mulch can also be moved to the site in tractor buckets and spread across the soil surface with the blade or bucket of the tractor. Obtaining an even mulch depth is extremely difficult using this method, and requires many passes of the equipment that invariably compacts the soil. An alternative is to deliver several yards of mulch to a planting island in the bucket or shovel of a tractor or excavator. After the seedlings are planted, mulch can be hand raked at the specified thickness to cover the island.

Mulch Storage – If wood fiber is stored for long periods of time, the materials should not be placed in piles taller than 10 ft. Fresh piles of wood fiber have the potential to spontaneously ignite in larger piles, creating a fire hazard and potential loss of material. Consider placing a plastic covering over the piles to keep moisture out during the winter because wet mulch is harder to apply through a mulch blower than drier mulch.

Seed Placement During Mulching – Seeds can be sown prior to or during mulch operation. Sowing that is done before mulching can be accomplished through dryland sowing methods or through hydroseeding. Applying seeds during the mulching operation is accomplished by placing seeds in a "seed metering bin" attached to most mulch-blowing equipment. This equipment meters seeds into the mulch as it is being applied. The rate at which the metering system delivers seeds can be adjusted and must be calibrated prior to mulching to obtain the desired seed density (See Section 10.3.1, Seeding, for seed calibration methods). Recalibration should be done when seed rates or mulching rates have been changed.

Fertilizers – It is difficult to evenly apply fertilizers through a mulch blower system. Outside of mixing fertilizers in the mulch prior to placing it into the mulch bins, fertilizing must be done in a separate operation, either before or after mulching. Applying fertilizer through a hydroseeding system after seedling establishment is one strategy for increasing available nutrients on the site. As discussed in Section 10.1.1, Fertilizers, the delayed timing of fertilization reduces the

Figure 10.20 – *Wood fiber mulch is applied on steeper slopes with mulch blowing equipment. Large trucks can hold between 75 and 100 yards of mulch (A) while smaller trucks can hold up to 25 yards (C). Mulch is pneumatically delivered to the site through an application hose which can reach several hundred feet up steep slopes (A) with still enough force for ample delivery of mulch (B).*

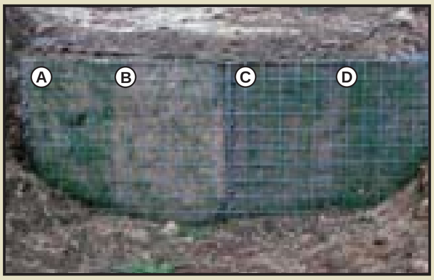
risk of nutrient leaching and increases the probability that nutrients will be available at the levels needed for established plants.

10.1.3.8 Erosion Mats

Erosion mats are manufactured blankets or mats designed to increase surface stability and control erosion. They are available in strips or rolls with a minimum thickness of 0.75 inch. Erosion control revegetative mats (ECRM) or rolled erosion controlled products (RECP) are applied directly to the soil surface for control of sheet erosion and to aid the establishment of vegetation. Turf reinforcement mats (TRM) are materials that are filled with soil when installed to increase surface soil strength (Kemp 2006).

There are a multitude of products on the market, with a range in design and costs. Figuring out which products will serve your project needs at the right price can be challenging. Several state departments of transportation periodically evaluate and compare the shear stress, soil erosion protection, longevity, and other characteristics for these products (Caltrans 2003; Kemp 2006) and these documents are usually available on the internet. Since the installed costs of erosion mats can be very expensive, it is important that the job is done right. Taking the time to select the appropriate erosion mats, native species mix, and seed placement techniques is essential for assuring that revegetation is successful. Small field trials using different species and erosion mats can help in these decisions (Figure 10.21).

***Figure 10.21** – Small field trials can help select the most appropriate species and materials for a project. The trial shown in this picture compared straw mat (A and B) with a polywoven mat (C and D). It also compared the growth of blue wild rye* (Elymus glaucus) *and California fescue* (Festuca californica) *(A and C). The first year results indicated that there was much better establishment of grasses on the polywoven erosion mat than the straw mat, yet no difference in species growth. Maintaining the trial for two years showed that California fescue outperformed blue wild rye. These results led to using California fescue and polywoven erosion mat for the project described in Inset 10.3.*



The same characteristics that create an optimum environment for seed germination in other mulches are also important to consider when selecting erosion mats. Typically, those materials that protect the seeds from drying out but allow light and space for germinating seeds to grow into seedlings will perform the best for revegetation establishment. The thicker erosion mats with the most loft should have better conditions for seedling establishment than thinner materials.

The drawbacks to erosion mats are generally not in the product itself, but in how it gets applied to the site. Poorly applied erosion mats can result in sheet and rill erosion under the fabric. To avoid this problem, several important measures should be taken when installing erosion mats. First, the surface of the soil must be smoothed to a uniform elevation before the mat is placed. This will assure that when the mat is pinned to the soil, it is in intimate contact with the soil surface. Second, the materials must be trenched or keyed into the soil at the upper reaches of the fabric. This will assure that the material does not move downslope. Third, as with all slopes being revegetated, concentrated water should be kept off these slopes.

Seeds must be sown on the site prior to installing erosion mats. This can be done using any type of seeding method (e.g., hydroseed, drill, or hand broadcast). Care must be taken during and after mat installation to avoid disruption to the seedbed. Unless the seeds are extremely small, sowing seeds over installed erosion mats is not recommended because larger seeds will hang up in the fabric. Small seeds can be applied over erosion mats if tackifiers are not used and if the timing is correct so sufficient rain will move it through the erosion mat to the soil surface.

Some manufacturers offer erosion mats that are impregnated with seeds, eliminating the need for sowing. This method is advantageous on steep slopes or soil-faced gabion walls (Inset 10.3) where placing seed prior to mat installation is very difficult. It is important to work directly with companies that provide these products by supplying them with source specific seeds and specifying appropriate sowing rates. For successful germination, seeded erosion mats must be installed so that the seeds and fabric are in direct contact with the soil.

10.1.3.9 Straw and Hay

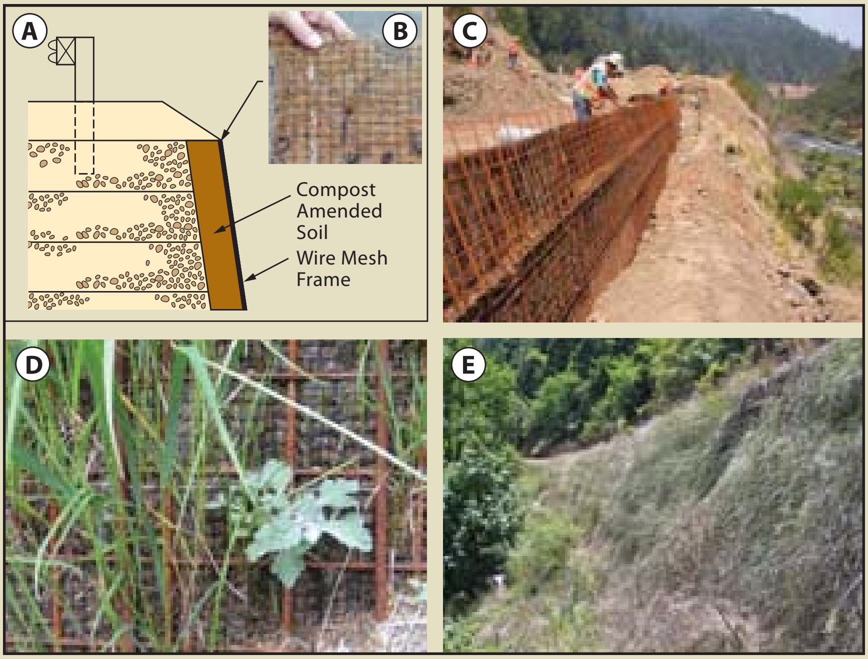
Straw and hay are long-fibered mulches used on many revegetation projects for seed cover and erosion control (Figure 10.18E). The terms straw and hay are often used interchangeably. However, straw is the stubble left over after seeds have been harvested from commercial seed or grain crops; hay comes from grass/legume fields usually grown for feed. When hay is harvested, it usually contains seeds from a variety of pasture species.

Inset 10.3 – Case Study: Erosion Mats with Native Grasses and Forbs

Reconstruction of the Agness-Illahe Highway required the construction of long sections of gabion walls. Since this highway is visible from the Rogue River (a designated "wild and scenic" river in southwestern Oregon) and is heavily traveled for recreational purposes, it was important that the gabion walls be visually screened using native plants. Gabions were designed to hold 12 inches of compost-amended soil (topsoil was not available) on the face of the walls by wire mesh frames (Figure A). Placement of seeds at the surface of the gabion wall was problematic. Several small plots using different erosion mats, seed mixes, seed rates and seed-attaching methods were tested to determine how to best meet the revegetation objectives (Figure 10.21).

The results from these trials indicated that we could attach native grass and forb seeds to erosion mats using a tackifier (B). In 2003, we applied our findings to the construction project. Needing approximately 33,000 ft^2 of gabion wall facing, we prepared the erosion mats by rolling them out on a road surface, applying California fescue (*Festuca californica*), gluing the seeds to the mat, and re-rolling the erosion mats.

The seeds held tightly to the fabric during transportation and handling. At the construction site, seeded mats were attached to the wire mesh at the face of the wall (C) and compost-amended soil was placed behind the screen and lightly tamped. The gabion walls were built in the summer of 2003, but the seeds did not germinate until late fall after several rainstorms. Figure D shows a close up section of wall with newly germinating seedlings coming through the erosion mat in late 2003, four months after wall construction. Figure E shows 20 to 30 ft high walls in July 2006, three years later, fully vegetated and effectively screening the walls from the road and river (Photo C courtesy of Scott Blower).



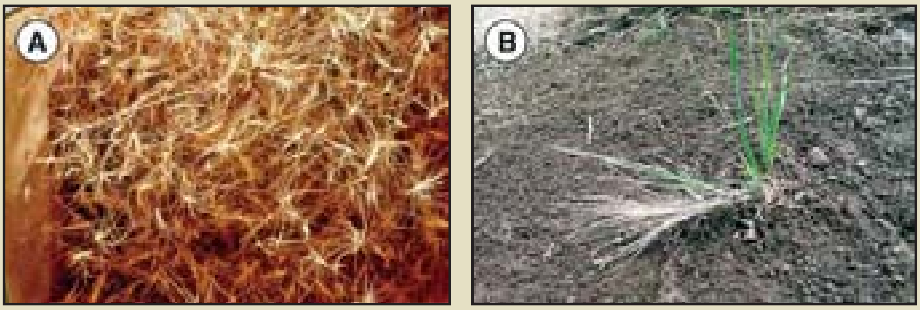
Straw and hay are often used on revegetation projects because they are available, comparatively inexpensive, and generally successful in establishing grass and forb plants from seeds. The long stems of these materials create loft, or high porosity, that keeps moisture near the soil surface where seeds are germinating. This creates a favorable environment for young seedlings by allowing sunlight to penetrate and protecting the young seedlings during the early stages of establishment.

Straw is often preferred over hay because it generally contains fewer undesirable seeds. The seeds that are contained in the straw may not always be considered inappropriate for use in revegetation projects. For example, straw from some grain production fields (e.g., rice straw) has seeds of species that are not adapted to wildland environments and therefore will not become established. Straw produced from native seed production fields, on the other hand, is desirable if the fields are grown from identified genetic sources and used for projects within the seed transfer zones. Not only does source-identified straw act as a mulch, but it also supplies extra native seeds to the site. Some native grass species grown for seed production are very difficult to harvest and clean. For these species, the seeds are not harvested, but baled together with the grass stems. The seeded bales are applied directly to the site through straw blowing equipment, accomplishing seeding and mulching in one operation (Figures 10.22 and 10.23). This method offers a practical alternative to species such as bottlebrush squirreltail (*Elymus elymoides*) or western needlegrass (*Achnatherum occidentale*) which can be difficult to harvest and clean.

Purchasing Straw and Hay – The drawbacks to using straw and hay are that these materials can contain seeds from undesirable species, are susceptible to wind movement, have limited application distance, and decompose in a relatively short time compared to other mulches. Introducing seeds of undesirable species from straw and hay sources is an important consideration when choosing a source. There are many examples where, in the urgency of erosion control, straw or hay from unknown sources was applied, resulting in the introduction of weed species. The assumption in most of these cases was that short-term control of soil erosion and sediment production outweighed the long-term introduction of undesirable plant species. The potential disastrous results from these assumptions need to be understood and agreed upon prior to applying hay or straw from unknown sources. Good integration of erosion control and revegetation planning can eliminate the need for last minute purchase and application of unknown or undesirable hay or straw sources.

A good source of straw is native seed production fields. Seed growers identify straw bales by genetic source, so it is important to be sure that the source-identified bales are appropriate for the geographic area of the project site. Because of the potential for introducing weeds to your project site, you must be very certain of the species present in the hay or straw you are applying to your site. Many states have certification programs that inspect fields and certify that the bales are "weed free." Be clear what "weed free" means when you purchase these materials. There can be other seeds in the bales that, while not considered weeds by the certifying state, might nevertheless be unwanted on your site. A conservative approach for non-certified seeds is to examine the fields that will be producing your bales and observe which species are present before they are harvested. It must be assumed that if a species of grass or forb is present in a

Figure 10.22 – *Seeds of some species are baled with straw because of the difficulty of seed harvesting and cleaning. The long awns of the squirreltail seeds (A) show how difficult collecting and handling these seeds can be. The squirreltail seeds are germinating from the heads of the seeds that came in the bales (B).*



hay field, seeds from these plants will show up in the bales.

Some species grown for native seed production are difficult to harvest and clean because of long awns (Figure 10.22). An alternative method of seed harvest for these species is to allow the seeds to ripen in the fields and bale the seeds and grass stems together. The seed bales are applied to the site through hay blowing equipment. The seeds are detached from the stem as it is blown through the equipment, falling to the surface of the soil and covered by the grass stems. This is an effective means of applying seeds and seed covering in one operation.

__Figure 10.23 –__ Straw blowers range in size from machines which can apply 30 to 60 bales per hour (shown here) to very large straw blowers that can shoot up to 20 tons per hour.

Some things to require when purchasing straw or hay are:

- Source must meet or exceed State Certification Standards for "weed free." Many states have straw certification programs. Where no standards programs exist, acceptance should be based on seed crop inspection reports and/or visual field inspections by the COTR prior to harvest. Standards may also be set by the Government and listed on individual task orders.
- Straw or hay must be baled and secured according to specifications listed on the Task Order. Generally, bales should be less than 100 lbs.
- Bales should not be allowed to become wet after harvest or during storage prior to delivery.

The quality of straw and hay varies between grass species. Rice straw, for instance, is wiry and does not readily shatter, which makes it more difficult to apply as compared to wheat, barley, or oats (Kay 1983; Jackson and others 1988). Native straw is generally longer and stronger than grain straw (Norland 2000). Yet within native grasses, some species have better properties as mulches than others. Larger stemmed grasses, such as blue wildrye (*Elymus glaucus*), mountain brome (*Bromus marginatus*), and bluebunch wheatgrass (*Pseudoroegneria spicata*) make good mulches because of the large leaves and stems.

Application – Straw and hay can be spread by hand or with a straw blower. For large jobs, using a straw blower is the most practical application method. There are many types of straw blowers available on the market, ranging from very small systems (Figure 10.23) that deliver from 30 to 180 bales per hour to large straw blowers that operate at rates up to 20 tons per hour. The distance that straw or hay can be blown depends on the hay blowing equipment, wind conditions during application, straw characteristics, and whether the material is being applied upslope or downslope (cuts or fills). When wind is favorable, straw can be shot up to 100 ft. However, when wind is blowing against the direction mulch is being applied, the distance is reduced. Because of the limited application range, this equipment is limited to sites adjacent to roads. The upper portions of steep, extensive slopes are typically not reachable by straw blowers.

When straw is used as a seed mulch, it is important that the application rates are not too deep that a physical barrier is formed. A minimum depth that has been shown to control evaporation is one inch (Slick and Curtis 1985). Applying too much straw will restrict sunlight and growing space for establishing seedlings. A rule of thumb is that some surface soil (15% to 20%) should be visible through the straw after application (Kay 1972, 1983; Jackson and others 1988). This equates to 1.5 to 2 tons per acre, depending on the type of straw and its moisture content.

Straw is susceptible to movement with moderate to high winds. Tackifiers are often applied over the straw to keep it in place (Kay 1978). Products such as guar and plantago are used with low quantities of hydromulch to bind straw together (Manufacturers have stated application rates for this purpose).Straw can also be crimped, rolled, or punched into the soil. These measures will stabilize the straw by burying portions of the stems into the soil and can increase erosion protection because of the more intimate contact of straw with the soil surface. The potential for compaction is increased with these treatments and the tradeoffs of offsetting surface stability with long-term soil productivity should be weighed.

10.1.3.10 Wood Strands

Wood strands are long, thin pieces of wood, produced from wood waste veneer. This product was developed as an effective erosion control alternative to straw and hay (Foltz and Dooley 2003). The advantages of wood strands over straw are that it is free of seeds, has a longer life, and is more resistant to wind.

Wood strands, like straw, form a stable cover with high porosity or loft, characteristics which are important for controlling soil moisture and temperature around the germinating seeds. The large spaces or pores created by the wood strands allow space, light, and protection for young emerging seedlings (Figure 10.13). Unlike straw, these materials keep their structure or porosity over time, and do not compress with snow or lose fiber strength through decomposition. While the performance of this new product as a seed cover has not been tested, it has all the characteristics of being an excellent seed cover. The application rates for wood strands are likely to follow the guides for straw – at least 15% to 20% of the soil surface should be visible. This is likely to be greater than the recommended rates for erosion control. Installing small test plots of varying thicknesses of mulch would be a good means to determine the appropriate thickness for optimum seed germination. Wood strands are delivered in different size bales and applied by hand or through straw blowing equipment (Figure 10.23). As with straw, this product is limited by the accessibility of the site by hay transportation and blowing equipment.

10.1.3.11 Litter and Duff

Litter is the layer of fresh and partially decomposed needles and leaves that cover the surface of most forest and shrub plant community soils. Duff is the dark, decomposed layer directly below the litter layer (leaves and needles are not identifiable in the duff layer) that is high in nutrients and humus. In addition to providing soil protection and nutrients, litter and duff can also contain dormant, yet viable, seeds from species that make up the forest or shrub plant communities. When litter and duff are collected, they should be matched to the appropriate revegetation site. For example, litter and duff collected from cool, moist sites should not be applied on hot, dry sites.

The depth that litter and duff accumulates will vary by species composition, age, and productivity of the plant community. Dense stands of ponderosa pine can produce thick layers of litter. More open forest stands on dry, less productive sites will have thinner layers of duff and litter (often less than an inch deep). The quality of the litter for erosion control and longevity varies by the dominant forest or shrub species. Pine needles provide the greatest benefit because the long needles interlock, reducing the potential of movement from rain or wind erosion (Figure 10.18F). Needles from species such as Douglas-fir are shorter and tend to compact, providing less surface stability. Litter from shrub plant communities provides less protection because the leaves are less interlocking. Nevertheless, these materials should not be overlooked because they can be a source for seeds and nutrients.

The collection of litter in the western states has typically been done manually by raking. Mechanizing the collection of litter has been done in the southern United States. The pine straw industry is well developed in this part of the country. Baling equipment has been developed for this industry and might be applicable to the western United States. Collection of needles and duff should be done during the summer and fall, when the litter and duff are completely dry. If these materials are not used immediately, they should be placed in small piles and completely covered by plastic to keep the materials dry. Excessive moisture can turn the piles into compost and possibly affect seed viability.

Inset 10.4 – Pine Straw Industry

Using forest litter as a mulch is not a new concept – pine needles have been a popular landscaping mulch in the southern United States for the past 25 years. The "pine straw" industry, as it is referred to, has been established to harvest needles in a sustainable manner from young plantations of southern pine species to meet this demand.

Litter and duff can be applied manually to disturbed sites. If viable seed rates are high in the litter and duff, and it does not contain large material, it can be applied in a variety of ways (e.g., hydroseeder, mulch blowing equipment).

One method for determining the amount of viable seeds in a litter layer is to actually conduct a germination test at the project site over a several year period by obtaining litter and duff from several potential collection areas and testing them on nearby sites. Like soil sampling, samples should be collected by obtaining a composite of subsamples of an area. Collect samples from each of the plant communities that are considered for litter collection and keep these samples separate. Establish test plots at sites that are representative of each revegetation unit (these can be reference sites). Each plot should be well marked (each corner identified with stakes and permanent labels identifying the litter source) and located where it will not be disturbed. Plots must be free of vegetation and top several inches of soil should be removed to eliminate potential seed sources. A known amount of litter (either by dry weight or by volume) should be spread across each plot. Visit the plots during the spring and count the number of seeds that are germinating. During the summer or fall, identify plant species and count individual plants in the plots. At the end of the assessment, calculate the number of seedlings per known volume or weight of litter material. These figures can then be used to determine the rate of litter to be applied.

10.1.4 TOPSOIL

10.1.4.1 Introduction

Topsoiling is the salvage, storage, and application of topsoil material to provide a suitable growing medium for vegetation and to enhance soil infiltration (Rauzi and Tresler 1978; Woodmansee and others 1978; NRCS 1994). Topsoiling has been found to increase plant cover and biomass through an increase in nutrient availability, water-holding capacity, and microbial activity, including mycorrhizae (Claassen and Zasoski 1994). It has also been found to increase the number of plant species native to the area. Bailey (2004) found that the application of 3 inches of topsoil over subsoil in eastern Washington increased the presence of native species by a factor of four and increased vegetative ground cover the first and second year by 20%.

While topsoiling has many beneficial effects for revegetation, topsoiling cannot recreate the original undisturbed soil. In the process of removing and reapplying topsoil, soils undergo a loss of 1) soil aggregation, 2) organic nitrogen, 3) arbuscular mycorrhizal fungi (AMF) inoculum, and 4) microbial biomass carbon (Visser and others 1984). Minimizing topsoil disturbance is preferred to topsoiling, especially on sensitive soils, such as those derived from granitic and serpentine bedrock (Claassen and others 1995).

10.1.4.2 Salvaging Topsoil

The removal of topsoil should only be done in areas that will be excavated, severely compacted, or buried with excavated material, such as fill slopes. These areas are usually identified early in the planning stages. During the assessment phase of the revegetation plan, a topsoil survey should be conducted to determine the depth and quality of the topsoil that will be excavated (See Section 5.5.1). Ideally, only the topsoil is removed in the excavation process. Mixing topsoil and subsoil together will dilute microbial biomass and mycorrhizal inoculum of the topsoil, which will decrease their effectiveness in reestablishing nutrient cycling.

Topsoil quality should be determined from laboratory tests and field surveys. Topsoils with high sodium, high salinity, very high or very low pH, or any other condition that may be toxic to plant growth should be avoided (Rauzi and Tresler 1978). If weeds are observed during the field survey, it should be assumed that the seeds of these species are present in the topsoil and these areas should be avoided. During topsoil excavation, the litter and duff layers are usually removed with the topsoil. These layers are sources of decomposed and partially decomposed organic matter. Under topsoil storage conditions, this material will undergo some decomposition, releasing nutrients. Separation of duff and litter from the topsoil prior to topsoil excavation should be considered when the duff and litter are to be used as a native seed source or soil cover.

It is best to excavate topsoil when soils are relatively dry. Under dry conditions, there is less potential to compact the soil or destroy soil aggregation. Dry topsoil should also store longer and maintain better viability than moist topsoil (Visser, Fujikawa, and others 1984). The period when topsoils are dry is generally limited to the beginning of the summer through the middle of fall, which may not always lend itself to construction schedules. Restricting topsoil excavation operations to dry periods should be considered for large topsoil piles or if topsoil will remain in piles for greater than one year.

Topsoil layers are typically removed with either the blade of a tractor or excavator bucket. Soil compaction should be minimized prior to removal, which requires keeping large equipment travel to a minimum. Topsoil is typically placed into berms at the bottom of fill slopes or top of cut slopes and stored there until it is reapplied. If salvaged in this manner, small piles are created and soil is minimally handled. Minimum berm dimensions are approximately 6 ft wide by 3 ft high, which is often not large enough for the amount of topsoil that needs to be stored. When this is the case, topsoil is trucked offsite to larger storage piles. Because of the potential for weed invasion, potential offsite topsoil storage areas should have a weed assessment conducted prior to selection of the site.

10.1.4.3 Storing Topsoil

The question often raised around storing topsoil is how long it can remain piled before it loses its viability. Studies have shown that stored topsoil can remain viable from 6 months (Claassen and Zasoski 1994) to several years (Miller and May 1979; Visser, Fujikawa, and others 1984; Visser, Griffiths, and others 1984,) but will decrease in viability after 5 years (Miller and May 1979; Ross and Cairns 1981).

Viability of stored topsoil is a function of moisture, temperature, oxygen, nitrogen, and time. Stockpiled topsoil has been compared to "diffuse composting systems" (Visser, Fujikawa, and others 1984) because, under optimum conditions, organic material in the topsoil will compost. Decomposition of organic matter in stored topsoil will reduce microbial biomass essential for nitrogen cycling (Ross and Cairns 1981) and fine roots that store mycorrhizal inoculum (Miller and May 1979; Miller and Jastrow 1992). Optimum environments for decomposition include high moisture, warm temperatures, and available nutrients, all conditions present in most topsoil piles. Climates with lower moisture and temperatures can be more favorable to long-term storage. A study in Alberta, Canada, for instance, revealed that topsoil had very little respiration or organic decomposition after three years in a stockpile due to the influence of the cold, dry climate (Visser, Fujikawa, and others 1984). Dry topsoils store longer and maintain greater populations of viable mycorrhizal fungi (Miller and Jastrow 1992). If a topsoil pile is to be held over winter in areas of moderate to high rainfall, it should be kept dry by covering with plastic (which will also keep the piles protected from erosion and weed establishment).

The size of the pile can also affect the viability of the topsoil. The interior of large piles maintain higher temperatures and are usually anaerobic, which can be detrimental to soil microorganisms. Microbial biomass levels and mycorrhizal fungi have been found to be very

***Figure 10.24** – Soil testing of salvaged topsoil can be used to calculate the thickness to apply in order to meet minimum nitrogen levels.*

A	Total soil nitrogen (or other nutrient of interest) in salvaged topsoil	0.14	%	From soil test of post construction soils - reported in gr/l, ppm, mg/kg, ug/g divide by 10,000 for %
B	Soil bulk density	1.1	gr/cc	Unless known, use 1.5 for compacted subsoils, 1.3 for undisturbed soils, 0.9 for light soils such as pumice
C	Fine soil fraction	70	%	100% minus the rock fragment content - from estimates made from sieved soil prior to sending to lab
D	Nitrogen for soil layer (A * B * C * 270) =	2,911	lbs/ac ft	Calculated amount of total nitrogen in 1 acre feet of soil
E	Minimum or threshold N levels	1,100	lbs/ac	Determined from reference sites or minimum thresholds from literature
F	Minimum topsoil application: E/D * 12 =	4.5	inches	The minimum thickness of topsoil to apply to meet minimum thresholds of nitrogen

low in the bottom of large stockpiles (Ross and Cairns 1981; Miller and Jastrow 1992). Most projects limit topsoil piles to 3 to 6 ft in height. This is not always possible, especially when topsoil storage space is limited. Under these circumstances, the size of the topsoil pile can be quite large. To reduce the negative effects associated with very large piles, topsoils should be salvaged dry and kept dry during storage. Large piles should be stored for as short a time as possible.

Standard specifications often call for temporary seeding of topsoil piles. The benefits of this practice are erosion control and maintenance of mycorrhizae inoculum through the presence of live roots. This practice should be evaluated for each project to avoid the introduction of undesirable plant species in the seeding mix if non-native species are used. Alternatives to this practice include hydromulching without seeds or covering with plastic.

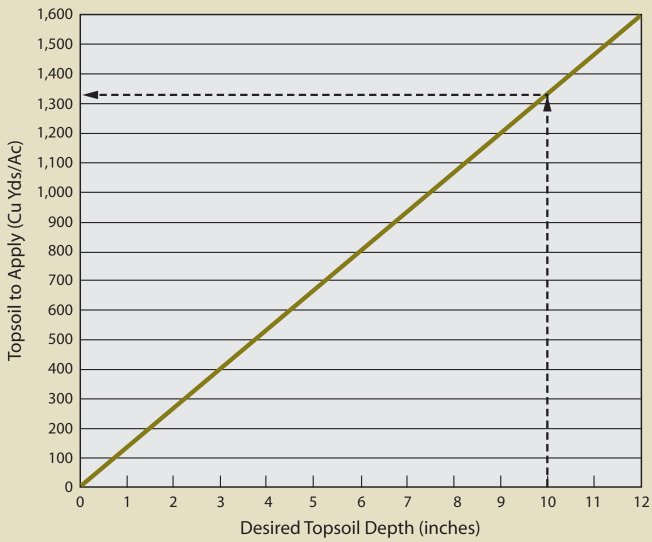
10.1.4.4 Reapplying Topsoil

The depth of topsoil application is generally based on the amount of topsoil available and the desired productivity of the site after application. As a rule, the deeper topsoil is applied, the higher the site productivity will be. If the objective is to restore a site to its original productivity, the placement of topsoil should be at a depth equal to or greater than the topsoil horizon of undisturbed reference sites. Sufficient topsoil quantities however, are rarely available in the quantities needed to restore disturbed sites to their original topsoil depths. This often leads to applying topsoil too thinly across a project site. There may be a minimum topsoil depth below which the application of topsoil is not effective. Research on a northern California road construction site (Claassen and Zasoski 1994) suggests that a depth of 4 to 8 inches was required for an effective use of topsoil. On sites where the subsoil is unfavorable for plant establishment (e.g., very high or low pH, high sodium, high salinity), minimum depths of greater than 12 inches of topsoil should be considered (Bradshaw and others 1982).

Determining minimum topsoil application depths can be based on the minimum amount of nitrogen required to establish a self-maintaining plant community. A threshold of approximately 700 kg/ha (625 lb/ac) of total nitrogen in the topsoil has been suggested for sustaining a self-maintaining plant community in a temperate climate (Bradshaw and others 1982). Claassen and Hogan (1998) suggest higher rates, especially on granitic soils, of 1,100 lb/ac total nitrogen. Using total nitrogen levels from soil tests of topsoil, the application thickness of topsoil can be determined using the calculations presented in Figure 10.24.

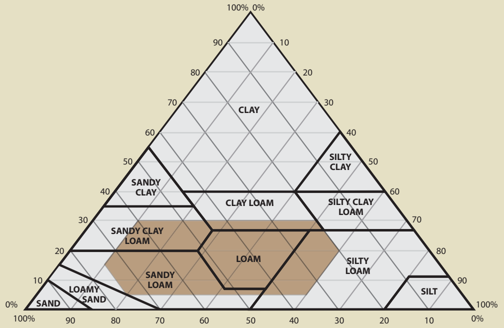
Once the desired topsoil depth has been established, it must be determined whether there is enough stored topsoil available to meet these standards. The quantity of cubic yards of topsoil required per acre can be determined based on the depth of topsoil from Figure 10.25. For example, if an average of 10 inches of topsoil is required on a project, approximately 1,350 yd^3/ac topsoil would be needed. If there is not enough topsoil to meet this depth, then less than full coverage of the site should be considered over reducing the desired thickness of the topsoil.

***Figure 10.25** – The quantity of topsoil to apply to achieve a specified topsoil thickness can be estimated by finding the desired depth of topsoil. For example, a 10-inch depth of topsoil would require 1,350 yd^3 of topsoil.*



Where topsoil quantities are limiting, it is important to develop a strategy that addresses the location the topsoil will be spread and the depth at which it will be applied. The strategy might concentrate topsoil in areas such as planting islands, planting pockets, or in a mosaic pattern that blends with the natural vegetative community. The non-topsoiled areas could be treated with other mitigating measures, such as organic matter incorporation or mulching.

***Figure 10.26** – Soil textures that are suitable as "loam borrow" are shown in light brown on the USDA textural triangle.*



10.1.4.5 Manufactured Topsoil

The term manufactured topsoil (also termed "engineered topsoil") is used to define a soil created to perform like, or develop into, topsoil. It is usually manufactured offsite and transported to the area where it will be applied. Manufactured topsoil is used in gabion walls, crib walls, or other bioengineered structures. It can also be used in planting pockets and planting islands.

Selecting the appropriate organic matter, soil texture, and soil amendments for manufactured topsoil will increase the success of the project. The basic components of a manufactured topsoil are the loam borrow, compost, and soil amendments (e.g., fertilizer or lime amendment).

***Loam Borrow* –** Loam borrow is any material that is composed of mineral particles meeting a suitable texture class (Figure 10.26). Loam borrow should have low coarse fragment content, not restrict plant growth, and be weed-free. This material can come from many sources, such as subsoils, river sands, and terrace deposits. Loam borrow must be tested and meet the general specifications shown in Table 10.6. If the loam borrow comes from subsoils or parent material, it should be assumed that beneficial soil microorganisms are not present and should be added when the soil is manufactured.

***Compost* –** The organic component of manufactured topsoil (See Section 10.1.5) is composted materials from of a variety of materials including yard waste materials (grass clippings, leaves, and ground wood of trees and shrubs), sawdust, and biosolids. The heat generated during composting effectively reduces pathogens, weeds, and insects that may be hazardous to humans and detrimental to reestablishing vegetation. Compost must be free of weed seeds and vegetative material that propagate weedy plants (e.g., blackberry canes). The material must be well-composted, or stable, which can be indirectly determined by a respirometry test or calculated using C:N obtained from laboratory testing of nitrogen and organic matter. A stable compost will have a low respirometry rate (<8 mg CO_2-C per g organic matter per day)

***Table 10.6** – General specification ranges for loam borrow used in manufactured topsoil. These can be modified depending on the soil characteristics of the compost and other soil amendments (modified after Alexander 2003b; CCREF and USCC 2006).*

Test Parameters	Test Methods	Loam Borrow
Physical Contaminates (man-made inerts)	Man-made inert removal and classification (TMECC 03.08-C)	<1%
Trace Contaminants	Arsenic, Cadmium, Copper, Mercury, Manganese, Molybdenum, Nickel, Lead (TMECC 04.06)	Meets US EPA, 40 CFR 503 regulations
pH	1:5 slurry pH (TMECC 04.11-A)	5.0 -7.5
Soluble Salts	Electrical conductivity using 1:5 Slurry Method (dS/m)	<5
Bioassay	% seedling emergence and relative seedling vigor (TMECC 05.05-A)	>80% of control
C:N Ratio	(TMECC 05.02-A)	<25

and low C:N (<25:1). A bioassay test which compares the rate of seedling emergence and seeds sown in compost to seeds sown in a control growing medium would be useful. Table 10.7 lists specified values for a series of tests that should be performed on composted materials used in manufactured topsoils.

To assure the delivery of high quality organic materials, compost should be obtained from a facility that participates in the Seal of Testing Assurance (STA) program (discussed in Section 10.1.5). These compost facilities will send the latest lab results of the material of interest. A listing of STA compost facilities can be found at http://www.compostingcouncil.org. If a STA composting facility is not close enough to the project, other sources will have to be considered and testing the compost will rest on you. This will involve sampling the compost piles and sending the samples to an STA lab (a listing can be found at the Composting Council's website). It is important that the compost piles be visually inspected prior to purchase to assure that noxious weeds are not present on or near the composting facility.

The compost application rates range from 10 to 30% by volume of the loam borrow. Section 10.1.5 discusses how to determine specific organic matter rates.

Other Amendments – Soil amendments, such as fertilizers, lime, and beneficial microorganisms, can be applied to the compost and loam borrow to bring the manufactured soil into acceptable ranges for pH, nutrients, and microbiological parameters. The type and amount of amendments to apply can be determined by conducting a lab analysis on a sample of the manufactured topsoil. The sample must be from a combination of loam borrow and compost at the expected mixing ratio. From the results of the soil analysis, a determination for the rates fertilizers (See Section 10.1.1), lime amendments (See Section 10.1.6), and beneficial organisms (See Section 10.1.7) can be made.

Large quantities of manufactured topsoil can be mixed in a staging area. Using the bucket of a front end loader, the compost and loam borrow can be measured out by volume. For instance, using a 5 yd^3 bucket, manufactured topsoil with a ratio of 25% compost and 75% loam borrow would have one scoop of compost applied to 3 scoops of loam borrow to produce 20 yd^3 of material. Additional amendments, such as fertilizers or lime materials, would be applied based on calculations for a 20 yd^3 pile. Once all the materials have been placed in the pile, it is thoroughly mixed using the front end loader.

Table 10.7 *– General specification ranges for composted materials for manufactured topsoil. These are generalized specifications that can be broadened depending on the soil characteristics of the loam borrow and site conditions (modified after Alexander 2003b; CCREF and USCC 2006).*

Test Parameters	Test Methods	Composted Material
Physical Contaminates (man-made inerts)	Man-made inert removal and classification (TMECC 03.08-C)	<1%
Trace Contaminants	Arsenic, Cadmium, Copper, Mercury, Manganese, Molybdenum, Nickel, Lead (TMECC 04.06)	Meets US EPA, 40 CFR 503 regulations
pH	1:5 slurry pH (TMECC 04.11-A)	5.0 -8.5
Soluble Salts	Electrical conductivity using 1:5 Slurry Method (dS/m)	<5
Bioassay	% seedling emergence and relative seedling vigor (TMECC 05.05-A)	>80% of control
% Moisture Content	% wet weight (TMECC 03.09-A)	30 - 60
Total Organic Matter	% by dry weight, loss on ignition (TMECC 05.07A)	25 to 60%
Stability	Respirometry. Carbon dioxide evolution rate - mg CO_2-C per g OM per day (TMECC 05.08B)	<8
C:N Ratio	(TMECC 05.02-A)	<25
Particle Size	% of compost by dry weight passing a selected mesh size, dry weight (TMECC 02.12-B)	* 3" (75 mm) 100% * 1" (25 mm), 90 -100% * 3/4" (19 mm), 65 -100% * 1/4" (6.4 mm), 0 -75% * Maximum particle length of 6" (152 mm)

Purchasing loam borrow, compost and topsoil requires a set of contract specifications that assure product quality. The specifications in Tables 10.6 and 10.7 were developed for the DOT by the Composting Council Research and Education Foundation (Alexander 1993b). The tests are based on Test Method for the Examination of Composting and Composts (TMECC) protocols. These are general quality guidelines and can be broadened or made more constraining depending on the specifics of the project. When considering purchasing these products from a manufacturer, it is important to request the latest lab analysis. An STA facility (See Inset 10.7 in Section 10.1.5) will have these reports available while others might not. It is important that these tests be run by STA laboratories. It is also good to visit the location of the loam borrow, compost, or topsoil sources to determine whether there are undesirable or noxious weeds on or nearby the piles. If undesirable or noxious weeds are present, do not purchase the materials.

10.1.5 ORGANIC MATTER AMENDMENTS

10.1.5.1 Background

High quality topsoil is not always available in the quantities needed to meet the objectives of a revegetation project. In such cases, infertile subsoils can be augmented by the incorporation of organic matter and other soil amendments. This practice can be an important tool to begin the process of rebuilding a soil and reestablishing native vegetation.

One immediate effect of incorporating organic matter into infertile subsoils is increased infiltration. Water that would typically run off the soil surface during rainstorms now enters the soil. Amended subsoils also have greater permeability, and often increased water storage. Changes in these factors can improve the overall hydrology of the site, making soil less susceptible to runoff and erosion.

Incorporation of organic matter can often improve plant establishment and growth rates, especially if composted organic matter is used. Composted organic materials increase soil nutrients and rooting depth, which can create better growing conditions for native plant establishment. The use of non-composted organic materials, such as ground wood residues, can restrict plant establishment for the first several years after incorporation because of the immobilization of nitrogen. In this section, we will discuss the substitution of non-composted organic matter when composted materials are not available, are too expensive, or are excessive distances from the project site. Sources of non-composted organic materials are almost always available on construction sites as a result of the clearing and grubbing of trees and shrubs, and can be made available through grinding or chipping operations.

Incorporated organic matter becomes the primary source of energy for soil organisms and, whether fresh or composted, is the driving force behind soil development. In the process of decomposition, soil organisms turn cellulose into complex organic compounds, while slowly releasing nutrients for plant growth. Some of the complex compounds act similarly to glues, sticking soil particles together into aggregates, which ultimately create soil structure. The slow decomposition of organic matter delivers a steady supply of nutrients to the establishing plant community for many years.

The strategy behind many current revegetation projects is to obtain immediate cover with the use of seeds, fertilizers, and other amendments, without considering what is needed for long-term site recovery. It is not uncommon to find good establishment of vegetative cover immediately (within a year) after revegetation work, but several years later find that it was not sustainable. Life expectancy of many revegetation projects has often been found to be very short (Claassen and Hogan 1998). Incorporating organic matter takes a different approach. This strategy puts more emphasis on the development of the soils and less on the quick establishment of vegetation. It is based on the premise that reestablishing native vegetation will create healthy, functioning soils on highly disturbed sites over time. This cannot happen without basic minimum soil components, such as an organic source, nutrients, and good soil porosity. These components of a soil must be in place if plant communities are to become sustainable. Incorporating organic matter into the soils of highly disturbed sites is an important component of meeting long-range revegetation objectives.

10.1.5.2 Set Objectives

Section 10.1.3 discussed the use of organic matter as seedbed or seedling mulch. When used as mulch, organic matter protects the soil surface from erosion, enhances seed germination, and, with time, breaks down and improves the surface soil properties. Applying organic matter on the soil surface is far easier and more practical than incorporating it into the soil. Why, then, incorporate organic matter?

- Improve soils of "difficult" parent materials,
- Increase water-holding capacity,
- Improve rooting depth,
- Improve infiltration and drainage, and
- Encourage quicker release and availability of nutrients and carbon.

Setting objectives clarify why this mitigating measure is being considered and helps define the appropriate sources and application rates for incorporated organic matter.

"Difficult" Parent Material – The parent material from which soils are derived often plays an important role in how soils will respond to disturbances. Soils originating from granitic rock respond poorly to the removal of topsoil. Subsoils from this parent material have very high bulk densities and low permeability rates. They can "hardset" when dry, restricting root growth

Inset 10.5 – How Much is Soil Water-Holding Capacity Increased by Incorporating Organic Matter?

To determine whether there will be an immediate increase in the water-holding capacity of a soil as a result of organic matter incorporation, a test can be performed using readily available supplies (Note: This should be considered a "relative" test for available moisture, since wilting point is not determined).In the field, collect a large amount of soil (at least several quart bags). Obtain samples of the organic matter amendment under consideration. Make 6 or more containers out of 3-inch PVC pipe by cutting them into 4-inch lengths. Secure cheese cloth with duct tape around the bottom of one tube. Make a flat "end" piece for the tubes by cutting a plastic sheet (or using an old CD) and secure it to the bottom as well.

In a bowl, mix several samples of organic matter to sieved soil (a mixing rate of 4.5 cups soil to 0.5 cups organic matter = 10% organic matter; 4 cups soil to 1 cup organic matter = 20%; 3.5 cups soil to 1.5 cups organic matter = 30%). Place each mix in a PVC tube and fill to the top (the soil should be held in the tube by the cheese cloth and plastic). Lightly tamp the container against a surface and fill to the top of the tube. Identify the mix of soil and organic matter. As a control, or comparison, one tube must have no organic matter in the sample. Place each container in a 5-gallon bucket or plastic trash can (which must be taller than the length of the tubes). Fill the bucket with water just to the tops of the tubes (you might have to fill the bucket up to the top a few times) and keep them in the bucket for at least 30 minutes, or as long as it takes to see thoroughly moistened soils.

Remove the tubes from the water and let them drain. After several hours, detach the plastic bottoms (the soil should be held together by the cheese cloth) and place the ends of the tubes on a large stack of newspapers or paper towels. The paper will remove the excess water held at the bottom of the tube. Replace paper towels as they become saturated (Note: Place the plastic bottoms over the top of the tubes to prevent the soil at the surface from drying).

After 24 hours, record the weight of each tube. Remove the soil from the tube and weigh the tube. Dry soil at 221 °F (105 °C) in a drying oven. Unless a drying oven is available, purchasing one can be expensive. An alternative is drying each sample in a crockpot. These inexpensive appliances can reach temperatures of approximately 200 °F and it is possible to dry several samples in a day. When the sample is dry, weigh the sample. Calculate the percentage of soil moisture for each soil mix using the following equations (be sure to subtract the tube weights from the soil):

% soil moisture = (wet soil weight – dry soil weight) / dry soil weight * 100

If there is no increase in % soil moisture with the additions of organic matter over the soil with no organic matter additions, it means that in the short term, applying organic matter will not improve water-holding capacity. For a more accurate assessment, contact analytical laboratories that perform soil moisture tests.

and increasing runoff (Claassen and Zasoski 1998). Any positive effects of deep tillage are often short-lived on granitic subsoils (Luce 1997) because they quickly return to high bulk densities and soil strengths. Granitic soils can benefit from the incorporation of organic matter, not only because of increased nutrients, but because soil physical properties are improved. Organic amendments lower bulk densities and help to form pathways for water entry, soil drainage, and root growth. Organic matter can also increase the water-holding capacity of these soils.

Soils derived from serpentine rock have also been identified as difficult to revegetate because of heavy metals, low water-holding capacity, low nutrient levels, and low calcium to magnesium ratio. When disturbed, these sites can take decades to revegetate, producing a continual output of sediments. Incorporating compost into serpentine soils can greatly improve revegetation success by increasing water-holding capacity (Curtis and Claassen 2005).

Water-Holding Capacity – The incorporation of organic matter can increase water-holding capacity of soils with less than 9% available water capacity (Claassen 2006). These include soils with sand, loamy sand, and some sandy loam textures, as well as soils high in rock fragments. Incorporating organic matter to increase water-holding capacity can be critical on arid or semi-arid sites, or sites with very little summer rainfall. The increase in moisture-holding capacity depends on the type of organic matter and the degree of decomposition. Non-decomposed (fresh) organic sources, such as large wood chips and shredded wood fiber, can actually decrease soil water-holding capacity because these large materials hold very little water (These materials can act similarly to gravels).A test for determining how much soil moisture will be increased or decreased by the incorporation of organic matter is described in Inset 10.5. From these results, the source and quantity of organic matter to incorporate can be determined.

Rooting Depth – For species that have deep rooting requirements, such as trees and some shrubs, incorporating organic matter into the subsoil can increase rooting depth. This can be beneficial for plant establishment and long-term site recovery, especially when applied to soils derived from "difficult" parent materials. Soils that are compacted can also benefit from deep incorporation of organic matter. The incorporation of organic matter to deeper levels is often accomplished by applying a thick layer of organic matter to the surface, and then incorporating it to the desired depths with an excavator or backhoe. It is important that the organic matter is thoroughly mixed through the soil profile during incorporation.

Infiltration and Drainage – The hydrology of most disturbed soils is improved with organic matter incorporation. The degree to which infiltration and permeability is improved depends on the size and shape of the organic source and application rates (see following sections). Finer textured soils lacking structure (e.g., clay loams, silty clay loams, and sandy loams) should have better infiltration and permeability when organic matter is uniformly applied. This objective is applied in areas where water quality issues are high.

Nutrients and Carbon – Applying organic matter can assure that nutrients and carbon are available to decomposing soil microorganisms, which are essential for rebuilding a healthy soil. Typically this objective is applied to soils that are low in nutrients and carbon (e.g., sites lacking topsoil).

10.1.5.3 Select Organic Materials

There is a range of organic material sources to consider. Developing a selection criteria based on the following characteristics can be helpful:

- Source of organic matter,
- Level of decomposition,
- Carbon-to-nitrogen ratio (C:N), and
- Size and shape of material.

Recognizing how these characteristics will help achieve the objectives for incorporating organic matter should guide the revegetation specialist in making the appropriate decision for each project.

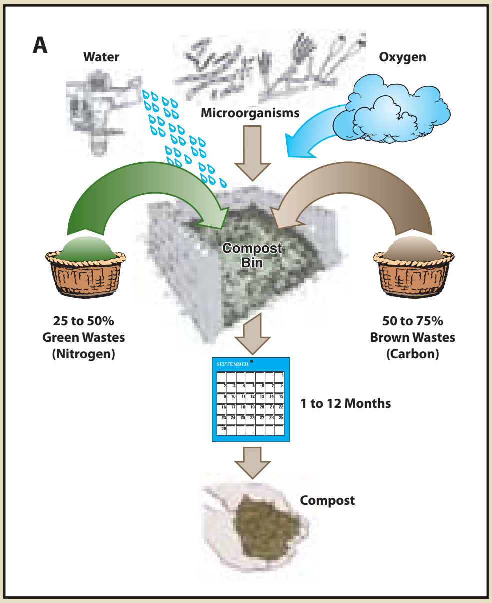
Organic Sources – Most available organic sources originate from waste byproducts of agriculture, forestry, and landscape maintenance. They include yard waste (lawn clippings, leaves), wood residues (sawdust, bark, branches, needles, roots, and boles of trees and shrubs from landscape maintenance, land clearing, logging operations, or mills), manures (poultry or

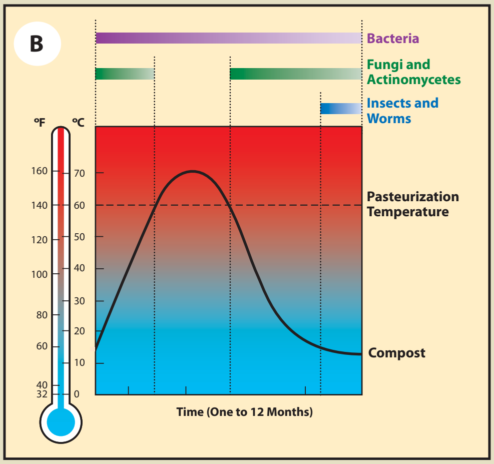
Inset 10.6 – Compost Production

The production and use of compost in the United States has flourished in the last 20 to 30 years as a result of a ban in many of states on yard wastes in landfills. Since 1988, the number of yard waste composting facilities in the United States has expanded from less than 1,000 in 1988 to over 3,500 in 1994. With the formation of the Composting Council in 1989, research in compost manufacturing has increased significantly.

Composting is the biological decomposition of organic matter under controlled aerobic conditions. To start the composting process, there must be organic matter, water, microorganisms, and oxygen (A). Heat is also needed, but is created by the microorganisms as they proliferate. Temperatures exceed levels necessary to kill most pathogens and weed species (B). With time, in a controlled composting environment, microorganisms release carbon dioxide and water from the organic matter. The rate at which these are released, and ultimately the composting time, is a function of the type of material being composted and the composting method.

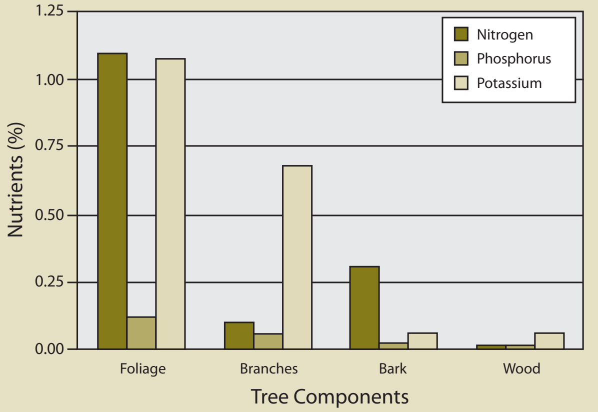
A variety of composting methods have been developed over the years. State-of-the-art facilities and equipment that control and monitor oxygen, moisture, CO_2, and temperature levels throughout the composting process can produce relatively uniform products. The picture shown in (C) is of a composting system that pumps oxygen through a pipe centered in the wrapped piles of compost. Temperature and carbon dioxide are controlled through a venting system (adapted from Epstein 1997).





cattle), agricultural waste products (fruits and vegetables) and biosolids (treated sewage sludge meeting EPA regulations). In the composting process, usually more than one source is used. A compost from one facility might include lawn clippings, leaves, yard waste, poultry manure, and ground wood fiber, while another facility might use yard waste, ground wood fiber, and biosolids. When biosolids are used in the composting process, the resulting material is referred to as co-compost.

__Figure 10.27 –__ Nutrients are held in different portions of the forest biomass, as shown for old growth Pacific silver fir. On a percentage basis, tree foliage is the storehouse for nutrients. Mulch derived from branches and foliage will have far greater nutrient content than mulch from bark and wood (adapted from Cole and Johnson 1981).



Each organic source has a unique nutrient composition. Green alfalfa, for example, has a very different nutrient makeup than organic matter derived from wood residues of cleared right-of-way. Even within sources, there are very different nutrient compositions (Figure 10.27). For example, most of the nutrients of trees are concentrated in the foliage and branches, and very little in the bole of the tree. A chipped slash pile composed of higher proportions of branches and foliage will contain far greater nutrients than a pile composed primarily of tree boles and, as such, would probably be a more preferred organic source.

As organic sources decompose, they contribute their combination of nutrients to the fertility of the soil. Knowing the source from which the organic matter was derived will give some indication of the amount of nutrients that might be supplied to the soil (Table 10.8). This information is important to determine whether target long-term nutrient levels will be achieved. Nutrient analysis reports should be obtained from facilities supplying the compost. Other sources of organic matter can be collected and sent to labs specializing in this type of testing (Inset 10.7).

Knowing the source of the organic matter might also identify contaminants that could potentially be harmful to plant growth. Additions of waste products, such as fly ash and municipal and factory waste products can potentially decrease the quality of an organic source. Testing these materials for contaminants, pH, soluble salts, and bioassay (Table 10.9) will identify potential problems with materials.

Level of Decomposition – Organic matter can be in various stages of decomposition; from fresh organic matter with minimal decomposition to compost that has undergone extensive decomposition. The level of decomposition is an important consideration when selecting an organic amendment. Additions of relatively undecomposed organic matter to the soil can have negative short-term effects on plant establishment and growth.

"Fresh" organic matter is recently ground or chipped material that has undergone very little decomposition. These materials usually have very high C:N and will immobilize soil nitrogen for months to several years after incorporation, depending on the characteristics of the organic source. Very slow establishment of plants

__Table 10.8 –__ C:N for common sources of organic matter (from Rose and Boyer 1995; Epstein 1997; Claassen and Carey 2004; Claassen 2006).

Materials	C:N Ratio
Wood - Ponderosa pine and Douglas-fir	1,200:1 to 1,300:1
Bark - Ponderosa pine and Douglas-fir	400:1 to 500:1
Wood - Red alder	377:1
Paper	170:1
Pine needles	110:1
Wheat straw	80:1
Bark - Red alder	71:1
Dry leaves	60:1
Dry hay	40:1
Leaves	40:1 to 80:1
Yard compost	25:1 to 30:1
Oat straw	24:1
Rotted manure	20:1
Alfalfa hay	13:1
Top soil	10:1 to 12:1

Inset 10.7 – The Seal of Testing Assurance (STA) Program

Just as many products at the local market have seals of approval (e.g., "Approved by the FDA" or "USDA Inspected"), the United States Composting Council operates an approval system for composting facilities. The Seal of Testing Assurance (STA) is a voluntary program that requires compost manufacturers to regularly test their composts using an approved third-party testing facility. The procedures for sampling and testing are outlined in the Test Methods for the Examination of Composting and Compost (TMECC) protocols. The STA program takes the worry out of purchasing compost because you know that you can be assured that the company is reputable. You can purchase compost from companies that do not participate in the STA program (when the job site is in the back country you might have to do this), but this leaves the sampling and testing up to you. This involves traveling to the compost piles, systematically collecting samples from the compost piles, sending them to a qualified lab to run TMECC tests, and interpreting the results when you get them back. STA laboratories can be found at <http://www.compostingcouncil.org> (after Alexander 2003).

should be expected when incorporating fresh organic matter unless a continuous source of supplemental nitrogen is applied (e.g., applications of slow release fertilizers, growing nitrogen fixing plants). Nevertheless, applying fresh organic matter to highly disturbed soils can have a positive effect on slope hydrology and surface erosion. Fresh organic matter can increase infiltration and permeability in poorly structured soils by creating pathways for water-flow.

Incorporating fresh organic matter is not generally practiced in wildland revegetation. However, considering the expense of purchasing and transporting composted materials to remote sites, as well as the availability and abundance of road right-of-way material that is typically burned for disposal, this is an option that should be considered. If shredded or chipped road right-of-way material is to be incorporated into the soil, it should be allowed to age as long as possible in piles. To increase the rate of decomposition, the piles should be moved several times a year to add oxygen.

Some organic sources have been stored in piles for long periods of time and are partially decomposed. They are darker in appearance than fresh sources, but the appearance of the original organic source can still be discerned (e.g., needles or leaves are still identifiable).

***Table 10.9** – General specification ranges for composted materials for manufactured topsoil (modified after Alexander 2003; CCREF and USCC 2006).*

Test Parameters	Test Methods	Composted Material
Physical Contaminates (man-made inerts)	Man-made inert removal and classification (TMECC 03.08-C)	<1%
Trace Contaminants	Arsenic, Cadmium, Copper, Mercury, Manganese, Molybdenum, Nickel, Lead (TMECC 04.06)	Meets US EPA, 40 CFR 503 regulations
pH	1:5 slurry pH (TMECC 04.11-A)	5.0 -8.5
Soluble Salts	Electrical conductivity using 1:5 Slurry Method (dS/m)	<5
Bioassay	% seedling emergence and relative seedling vigor (TMECC 05.05-A)	>80% of control
% Moisture Content	% wet weight (TMECC 03.09-A)	30 - 60
Total Organic Matter	% by dry weight, loss on ignition (TMECC 05.07A)	25 to 60%
Stability	Respirometry. Carbon dioxide evolution rate - mg CO_2-C per g OM per day (TMECC 05.08B)	<8
C:N Ratio	(TMECC 05.02-A)	<25
Particle Size	% of compost by dry weight passing a selected mesh size, dry weight (TMECC 02.12-B)	* 3" (75 mm) 100% * 1" (25 mm), 90 -100% * 3/4" (19 mm), 65 -100% * 1/4" (6.4 mm), 0 -75% * Maximum particle length of 6" (152 mm)

These materials are sometimes referred to as "aged." Because only partial decomposition has occurred, C:N is lower than fresh organic matter. Nitrogen immobilization, however, should still be expected for a significant period of time after incorporation. Aged organic sources have not typically undergone extensive heating, like composts, and they can contain seeds of undesirable weeds.

Compost results from the controlled biological decomposition of organic material. The resulting heat generated in the process sanitizes the material. The end product is stabilized to the point that it is beneficial to plant growth (Alexander 2003a, 2003b). During the early stages of composting, heat is generated at temperatures that are lethal to weed seeds, insects, and pathogens (Inset 10.6). Fresh, moist compost piles will usually generate heat in the first few days of composting, reaching 140 to 160 °F, which will kill most pathogens and weed seeds (Epstein 1997; Daugovish and others 2006). The resulting material is a relatively stable, sanitized product that is very dark brown to black in color. Composts are very suitable materials for increasing the water-holding capacity of sandy soils, increasing nutrient supply, and enhancing soil infiltration and permeability rates.

Carbon-to-Nitrogen Ratio **–** The carbon-to-nitrogen ratio (C:N) is one of the most important characteristics to consider when selecting a source of organic matter. It is an indicator of whether nitrogen will be limiting or surplus (See Section 5.5.3.1). The higher the C:N, the greater the likelihood that nitrogen will be unavailable for plant uptake. When an organic source with high C:N is incorporated into the soil, carbon becomes available as an energy source for decomposing soil organisms. Soil microorganisms need available nitrogen to utilize the carbon source. Not only do microorganisms compete with plants for nitrogen, they store it in their cell walls, making it unavailable for plant growth for long periods of time. As the carbon sources become depleted, the high populations of soil microorganisms die and nitrogen is released for plant growth.

When C:N is greater than 15:1, available nitrogen is immobilized. As ratios dip below 15:1, nitrogen becomes available for plant uptake. Most fresh and aged organic sources have C:N greater than 15:1 (Table 10.8) and will immobilize nitrogen for some period of time when incorporated into the soil. When these same materials are composted, C:N approaches or even falls below 15:1. These materials will then provide a source of nitrogen to the soil. Co-composts, for instance, can have ratios between 9:1 and 11:1, indicating they are a ready source of available soil nitrogen. Since these materials provide nitrogen, they are often considered fertilizers (Ratios below 10:1 are typically labeled as fertilizers).

The period of time that nitrogen remains immobilized in the soil is dependent on several factors:

- ***Climate.*** High moisture and warm temperatures are important for accelerating decomposition rates. For example, organic matter will decompose faster in the coast range of Oregon than in the mountains of Idaho.
- ***Quantity of incorporated organic matter.*** The more organic matter that is applied, the longer the immobilization. A small amount of incorporated sawdust will immobilize very little nitrogen as compared to several inches of the same material.
- ***C:N of organic amended soil.*** The combined C:N of soil and incorporated organic matter gives an indication of how the type and rate of incorporated organic matter will affect the soil C:N. An amended soil with a high C:N will have a longer immobilization period than a soil with a lower C:N.
- ***Size and shape of organic matter.*** The more surface area of the organic source, the faster decomposition will take place. A fine compost will decompose faster than a coarse, screened compost.
- ***Nitrogen fertilization or fixation.*** Nitrogen supplied from fertilizers or nitrogen-fixing plants will speed up decomposition rates.

It is not easy to predict how long nitrogen will be immobilized in a soil. The variety of available organic sources, unique soil types, and range of climates of the western United States make this difficult. For practical purposes, it should be assumed that without supplemental additions of nitrogen (from fertilizers or nitrogen-fixing plants), the immobilization of nitrogen in soils with high C:N will be in the order of months, if not years. To give some idea of decomposition rates, Claassen and Carey (2004) found that partially composted yard waste with a C:N of 18:1 took over a year for nitrogen to become available under aerobic incubation testing conditions.

A high C:N might be beneficial to soil aeration and water movement because it does not break down as fast as material with lower C:N. For example, the incorporation of alfalfa hay (C:N =13:1) will decompose quickly, and the effects on soil structure might be short-lived. On the other hand, wheat straw (C:N = 80:1) or pine needles (C:N = 110:1) can be effective for several years. High C:N materials are also a longer-term energy source to soil organisms that help create a stable soil structure.

Nitrogen based fertilizers can be applied to offset higher soil C:N and make soil nitrogen available for plant growth. Section 10.1.1 discusses fertilizer strategies for reducing the effects of high C:N soils.

Size and Shape – The range in sizes and shapes of organic matter plays a role in how quickly organic matter breaks down in the soil. Particles with greater surface area to volume ratios should decompose faster than particles with less surface area to volume. Chipped wood, for instance, has a low surface area to volume ratio and would take longer to break down than long strands of ground wood or fine screened sawdust, which have greater surfaces areas.

The particle size and shape of the organic source can also be important in slope hydrology by increasing infiltration and permeability rates. Long, shredded wood fiber, for example, can create long passageways for water. If applied at high enough rates, long fibers can overlap, creating continuous pores that will increase drainage rates. Wood chips applied at the same rates are less likely to form continuous routes for water drainage because of their shape.

Large undecomposed wood can significantly reduce soil water storage due to low water-holding capacity of the material. Incorporating large, undecomposed woody organic matter into soils with low water-holding capacities should be tested first to determine its effect (See Section 10.1.5.1).

10.1.5.4 Determine Application Rate

The rates for applying organic matter should be based on the objectives for organic matter incorporation. Each objective discussed in Section 10.1.5.2 will yield different application rates. For example, a project objective to increase permeability would require the addition of 6 inches of compost mixed into 24 inches of soil. This is a far greater quantity than if the objective was to increase nutrient supply, which would require 2 inches of compost added to the top 12 inches of soil.

Determining rates of organic matter needed to improve nutrient status can follow the process outlined for calculating fertilizer rates in Section 10.1.1.2. If a nutrient, specifically nitrogen, is found to be deficient, the amount of organic material to apply must be determined. A nutrient analysis is necessary to make these determinations. Figure 10.28 gives an example of how to calculate the amount of organic matter to incorporate to meet minimum levels of nitrogen.

When organic matter is used to increase infiltration and permeability of a soil, a rate of 25% organic matter (by volume) to 75% soil (by volume) has been suggested by several researchers (Claassen 2006). This would require 4 inches of organic matter be incorporated for every 9 inches of soil. Actual field trials could be installed prior to construction to measure the effects

***Figure 10.28** – The following calculations can be used to determine the amount of compost to apply to a site. They are based on laboratory test results of the compost and threshold nitrogen levels obtained from reference sites.*

A	Total nitrogen (or other nutrient of interest) in compost	10	lbs/cu yd	From laboratory report — most labs will report out nutrients in lbs/cu yd of material
B	Nitrogen deficit	769	lbs/ac	Determine from reference sites or minimum thresholds from literature (See Figures 10.1 and 10.2)
C	Minimum application rates: B/A =	77	cu yd/ac	**Volume** of compost to apply to the site to meet minimum thresholds
D	Minimum application depth: C/135 =	0.6	in	**Thickness** of compost to apply to the site to meet minimum thresholds

of soil amendments on infiltration. By incorporating several rates of organic matter on plots in disturbed reference sites near the project, the infiltration rates of each treatment could be determined using rainfall simulation equipment.

If the objective for incorporating organic matter is to increase the soil's available water-holding capacity, the rate of organic matter application should be based on achieving a total available water-holding capacity for the desired vegetation of the project area (Setting these targets is discussed in Section 5.3).Inset 10.5 shows one method of determining relative water-holding capacity of amended soils.

10.1.5.5 Assure Product Quality

Purchasing compost requires a set of contract specifications that assure product quality. Table 10.9 is a "model specification" developed for the Department of Transportation (DOT) by the Composting Council Research and Education Foundation (Alexander 1993b) for composts used as soil amendments on roadways. The tests are based on the Test Method for the Examination of Composting and Composts (TMECC) protocols. These are general quality guidelines and can be broadened or made more constraining depending on the specifics of the project. When considering purchasing compost or any other type of organic matter from a manufacturer, it is important to request the latest lab analysis. A Seal of Testing Assurance (STA) facility (Inset 10.7) will have these reports available while others might not. It is important that these tests be run by STA laboratories. It is a good practice to visit the location of the organic sources to determine whether there are undesirable or noxious weeds on or nearby the piles. If these species are present, materials should not be purchased.

10.1.6 LIME AMENDMENTS

10.1.6.1 Introduction

Agricultural lime is used when soil pH of a disturbed site needs to be raised to improve plant survival and establishment (See Section 5.5.5, pH and Salts). Liming low pH soils improves plant growth by 1) reducing aluminum toxicity, 2) increasing phosphorus and micronutrient availability, 3) favoring symbiotic and non-symbiotic nitrogen fixation, 4) improving soil structure, and 5) enhancing nitrification (Havlin and others 1999).

Each plant community has an optimal pH range. Plant communities dominated by conifers, for instance, function well between pH 5.0 to 6.5, whereas grass-dominated plant communities in arid climates perform well between pH 6.5 and 8.0. Liming is not an easy operation on drastically disturbed lands. Liming materials must be incorporated into the soil profile for maximum effectiveness. This application is very difficult on steep rocky slopes, which are typical of road construction in mountainous terrain.

10.1.6.2 Set pH Targets

It is important to set a realistic post-construction target pH when considering liming because large quantities of lime are needed for even small changes in soil pH. For example, raising an existing soil pH of 5.5 to pH 6.5 takes nearly twice the amount of lime necessary to raise it to pH 6.0. A half point pH difference in this case can result in an increase of over 1,000 lb/ac in application rates.

***Table 10.10 –** Liming materials are rated by how well they neutralize the soil using pure limestone as the baseline of 100%. The rating system is called calcium carbonate equivalents (CCE). Values for some commercially available products are shown below (Campbell and others 1980; Havlin and others 1999).*

Material	Chemical Formula	CCE
Slag	$CaSiO_3$	60-90
Agricultural limestones	$CaCO_3$	70-90
Marl	$CaCO_3$	70-90
Pure limestone	$CaCO_3$	100
Pure dolomite	$CaMg(CO_3)_2$	110
Hydrated lime, slaked lime, builders' lime	$Ca(OH)_2$	120-135
Burned lime, unslaked lime, quicklime	CaO	150-175

As discussed in previous sections, it is important to understand the characteristics of the reference site topsoils and try to recreate these conditions after construction. If the post-construction surface soils have a lower pH than the reference site topsoils, then liming can be used to raise pH. On a project where topsoil is removed and not replaced, the difference between the pH of the topsoil and the subsoil should be determined. When the pH of the subsoil is significantly lower than the topsoil, liming to raise soil pH to reference topsoil levels (target levels) should be considered. Although it might not always be practical to raise pH of post-construction soils to reference topsoil values, a minimum pH target of 5.5 should be considered for most sites. This minimum standard would make most soils below pH 5.5 good candidates for liming.

10.1.6.3 Select Liming Materials

There are several types of liming materials commercially available (Table 10.10) and selection should be based on costs, reactivity, effects on seed germination, and composition of the material. All liming materials will raise soil pH, but not at the same level as pure limestone. To account for this, all commercially available liming materials are rated against pure limestone for neutralizing effects. The rating system is called calcium carbonate equivalent (CCE). Burnt lime (CaO) for instance, might have a CCE of 150, which means that it has a 50% greater neutralizing capacity than pure limestone and much less of this material needs to be applied to increase pH. A low CCE material, such as slag, might have a CCE of 60, which means that it has 40% less neutralizing capacity. Liming materials with high CCE, like $Ca(OH)_2$ (slaked lime, hydrated lime, or builders lime) and CaO (unslaked lime, burned lime, or quicklime), can be caustic to germinating seeds and, if used, should be applied several months before sowing (Havlin and others 1999).

The particle size of the liming material determines how quickly the pH of a soil will increase. The finer the material, the faster soil pH will increase. For instance, a lime material passing a 100-mesh screen reacts faster and takes less quantity than material passing a 50-mesh screen. Finer lime materials are more expensive to purchase. If very fine lime is to be used in surface application, it should meet the following size requirements: 100% passing a 100-mesh sieve and 80% to 90% passing a 200-mesh sieve.

10.1.6.4 Determine Liming Rates

Determining how much liming material to apply is based on these factors:

- ***Soil texture.*** Soil texture plays an important role in lime requirements because the higher the clay content, the more lime must be added to the soil. A soil with a clay loam texture requires over 3 times more lime to raise the pH from 5.0 to 6.0 than a sandy soil. This is because finer textured soils and organic matter have a higher propensity to attract and store bases released from liming materials (Inset 10.8).
- ***Soil organic matter.*** Soil organic matter (in humus form) has a high CEC and requires more lime material to raise the pH.
- ***Percentage of rock fragments.*** Rock fragments have little to no CEC because they are massive and typically unweathered. Rocky soils will require less lime materials to raise pH.
- ***Depth of liming material.*** Lime materials are relatively insoluble and only change the pH of the soil around where they were placed. Liming rates are adjusted based on the soil depth to which the lime material is mixed.

Inset 10.8 – Cation Exchange Capacity (CEC)

The capacity of a soil to hold positive ions (referred to as bases or cations) is called the cation exchange capacity (CEC). A soil with a high CEC holds a much greater amount of cations, such as calcium and magnesium, than a soil with low CEC. For this reason, a high CEC soil requires more liming material to raise it to the same pH level. Cation exchange capacity is directly related to the amount of clay and organic matter present in the soil – the higher the clay or organic matter content, the higher the CEC. Rock fragments have little or no CEC, since they are massive in structure. Rates of liming on high coarse fragment soils must be reduced proportionally.

Figure 10.29 *– This spreadsheet, along with Figure 10.30, provide the steps necessary for determining the approximate amount of liming material to apply.*

A	pH of disturbed soil:	5		From pH test of disturbed soils
B	Target pH:	6		Target pH of reference site topsoil
C	Soil texture:	sandy loam		From field surveys of disturbed soils
D	Rock fragments:	35	%	From field surveys of disturbed soils
E	Incorporation depth:	0.3	feet	The depth the lime material will be incorporated
F	Limestone equivalent for disturbed soil pH	900	lbs/ac	From Figure 10.30 (C)
G	Limestone equivalent	2,800	lbs/ac	From Figure 10.30 (D)
H	(G - F) * (E /0.58) * (100 - D) / 100	639	lbs/ac	Amount of limestone to raise soil to target pH
I	Type of liming material:	dolomite		Based on availability and cost of material
J	CCE of liming material:	110		From Table 10.10
K	H / (J /100) =	581	lbs/ac	Total amount of material to apply

- ***Lime material composition.*** Each liming material is rated by how well it neutralizes the soil. Less materials with high CCE (See Section 10.1.6.3) are required as compared to low CCE materials.
- ***Fineness of liming material.*** The fineness of the liming material determines how quickly the pH will change. Very fine materials change pH quicker than coarse materials. Therefore, less quantity of finer grade materials will be required for immediate pH soil change.

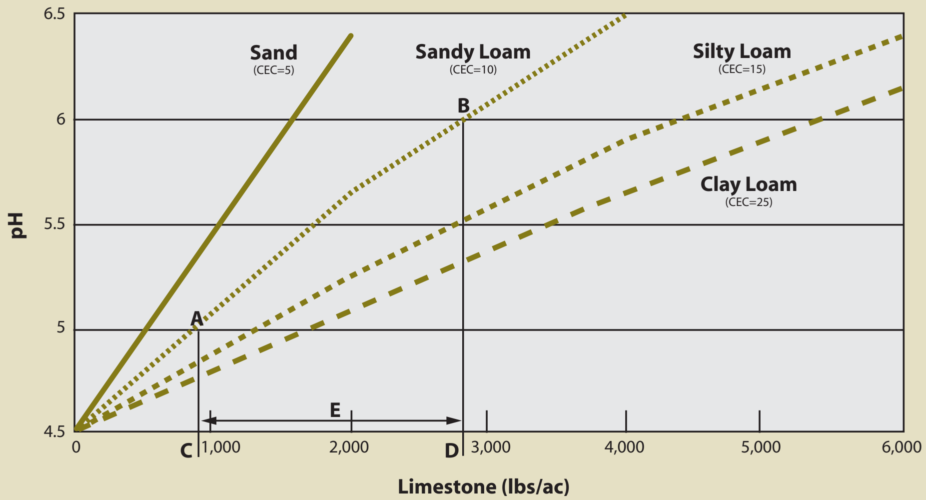
There are two methods for determining liming application rates: approximation and SMP (Shoemaker-McLean-Pratt) Buffer methods. For an initial estimate of how much liming material might be needed to raise soil pH to target levels, the approximation method can be employed. However, if liming will actually be done on a revegetation project, the SMP Buffer method should be used for calculations.

Approximation Method **–** For a quick approximation of lime application rates, the calculations shown in Figure 10.29 and Figure 10.30 are used. In the examples shown in these two figures, the topsoil was removed, leaving a gravelly, sandy loam subsoil at the surface. This material had a pH of 5.0. The target pH, based on the reference site for this area, was 6.0. The site was on a very steep slope where incorporating the limestone was not feasible (See Section 10.1.6.5). It was therefore decided to place the lime on the surface of the soil through hydroseeding operations. The surface had been left rough so that, over time, some of the liming materials would naturally become incorporated into the surface through soil movement. The incorporation depth was set between 3 to 4 inches (0.3 ft) based on this assumption.

Generalized curves shown in Figure 10.30 were used to determine the amount of limestone to add to raise the pH. On the baseline of the graph, rates of limestone in lb/ac that correspond to the surface soil pH (C = 900) and the target pH (D = 2,800) were determined from pH levels located on the sandy loam curve. The rate of limestone for the surface soil was subtracted from the target rate to give the quantity of limestone to add to 7 inches of soil (the depth of incorporation upon which these graphs were based). In this example 1,900 lb/ac of limestone was needed to achieve the target pH (2,800 less 900). This rate was subsequently reduced to 639 lb/ac to compensate for the volume of rock fragments and the shallow incorporation depth (3 inches instead of 7 inches). Since dolomite, which has a higher CCE value, would be applied, there would be less of this material needed (581 lb/ac).

SMP Buffer Method **–** For much greater accuracy, lab testing facilities offer the SMP Buffer Method for determining the lime requirement for a disturbed soil. The results from this test are reported in a table that includes the quantity of lime needed to raise the soil sample to pH 7.

Figure 10.30 *– This chart can be used to approximate the liming application rates for disturbed soils. The chart is based on measuring pH changes of four soil textural classes as limestone is incorporated into the surface 7 inches of soil (chart modified from Havlin and others 1999). For example, a sandy loam soil has an existing pH of 5.0 (A) and a target pH after liming of pH 6.0 (B). The amount of limestone to apply (E) is 1,900 lb/ac, which is calculated by subtracting 900 (C) from 2,800 (D). More accurate lab results obtained from the SMP Buffer method for determining lime requirements can be substituted for values obtained in this graph.*



The information can be graphed and used in a similar fashion to the example in Figure 10.30. The SMP test is well adapted for soils with pH values below 5.8 and containing less than 10% organic matter (McLean 1973).

10.1.6.5 Apply Liming Materials

Limestone materials are commonly applied in powder form through fertilizer spreaders or hydroseeding equipment. Fine limestone materials can be difficult to apply in dry form through fertilizer spreaders. Pelletized limestone, which is very finely ground material that has been processed into shot-sized particles, is easy to handle and can be used in fertilizer spreaders. Hydroseeding equipment, however, is probably the best method for spreading liming materials, especially very fine liming materials.

Since liming materials are relatively insoluble in water, surface applications of lime, without some degree of soil mixing, renders the lime ineffective for immediate correction of subsoil acidity. Several studies have indicated that it can take more than a decade for surface-applied lime (not incorporated) to raise soil pH to a depth of 6 inches (Havlin and others 1999). It is important, therefore, to incorporate liming materials into the soil at the depth where the pH change is desired.

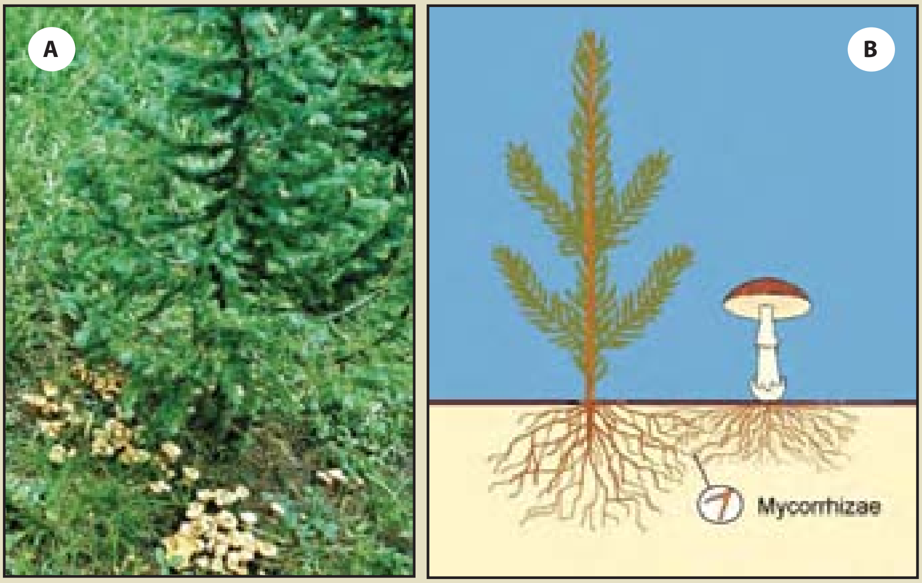
Incorporation can be accomplished on gentle slope gradients using tillage equipment, such as disks and harrows (See Section 10.1.2, Tillage). Liming materials can be mixed on steep slopes using an excavator. However, if equipment is not available for mixing on steep sites, applying very fine liming materials through hydroseeding equipment is a possible way of raising pH. This method requires the use of very finely ground limestone (Havlin and others 1999). This product raises pH faster, and depending on the soil type, can move a short distance into the soil surface. Nevertheless, with surface-applied limestone, it should be assumed that soil pH will not change much deeper than 3 inches below the soil surface.

10.1.7 BENEFICIAL SOIL MICROORGANISMS

10.1.7.1 Background

Beneficial microorganisms are naturally occurring bacteria, fungi, and other microbes that play a crucial role in plant productivity and health. Some types of beneficial microorganisms

Figure 10.31 *– Many plants rely on symbiotic relationships to survive and grow in nature (A). The mushrooms under this spruce are the fruiting bodies of a beneficial fungus that has formed mycorrhizae on the roots (B).*



are called "microsymbionts" because they form a symbiotic (mutually beneficial) relationship with plants. In natural ecosystems, the root systems of successful plants have several microbial partnerships that allow them to survive and grow even in harsh conditions (Figure 10.31). Without their microsymbiont partners, plants become stunted and often die. Frequently, these failures are attributed to poor nursery stock or fertilization, when the real problem was the absence of the proper microorganism.

As discussed in Section 5.3.5, beneficial microorganisms should be considered as part of an overall strategy to conserve existing ecological resources on the site, including existing beneficial soil microorganisms. These strategies include:

- Minimizing soil disturbance,
- Conserving and reapplying topsoil and organic matter,
- Leaving undisturbed islands or pockets on the project site, and
- Minimizing use of fast-release fertilizers.

On projects where soil disturbance will be minimal, or where healthy topsoil is still present and contains functional communities of beneficial microorganisms, reintroducing the organisms will usually not be necessary. However, most road projects involve severe disturbances and so healthy populations of beneficial microorganisms may be depleted or even absent. Soil compaction and removal of topsoil which is routine during road construction is particularly detrimental to beneficial soil microorganisms. Also, beneficial bacteria and fungi do not survive in soil in the absence of their host plants and so are killed during soil removal and stockpiling. Reintroducing beneficial microorganisms is therefore a key part of roadside revegetation.

Appropriate beneficial microorganism can be reintroduced by "inoculating" seeds as they are sown in the field or in the nursery, or by introducing the microorganism in the planting hole. Inoculated plants may establish more quickly with less water, fertilizer, and weed control, thereby reducing installation costs. Healthy, sustainable plant communities are our ultimate goal in roadside revegetation; inoculation can help accelerate the process.

The two most important microsymbionts for revegetation projects are mycorrhizal fungi and nitrogen-fixing bacteria.

10.1.7.2 What are Mycorrhizae?

Mycorrhizae are one of the most fascinating symbiotic relationships in nature. "Myco" means "fungus" and "rhizae" means "root"; the word "mycorrhizae" means "fungus-roots." The host plant roots provide a convenient substrate for the fungus, and also supply food in the form of simple carbohydrates. In exchange for this free "room-and-board", the mycorrhizal fungus offers benefits to the host plant:

Increased Water and Nutrient Uptake **–** Beneficial fungi help plants absorb mineral nutrients, especially phosphorus and micronutrients such as zinc and copper. Mycorrhizae increase the root surface area, and the fungal hyphae access water and nutrients beyond the roots (Figure 10.32A). When plants lack mycorrhizae, they become stunted and sometimes chlorotic ("yellow") in appearance.

Stress and Disease Protection **–** Mycorrhizal fungi protect the plant host in several ways. With some fungi, the mantle completely covers fragile root tips (Figure 10.32A) and acts as a physical barrier from drying, other pests, and toxic soil contaminants. Other fungal symbionts produce antibiotics that provide chemical protection.

Increased Vigor and Growth **–** Plants with mycorrhizal roots survive and grow better after they are planted out on the project site. This effect is often difficult to demonstrate but can sometimes be seen in nurseries where soil fumigation has eliminated mycorrhizal fungi from seedbeds. After emergence, some plants become naturally inoculated by airborne spores and grow much larger and healthier than those that lack the fungal symbiont (Figure 10.32B).

Mycorrhizal fungi form partnerships with most plant families, and three types of mycorrhizae are recognized:

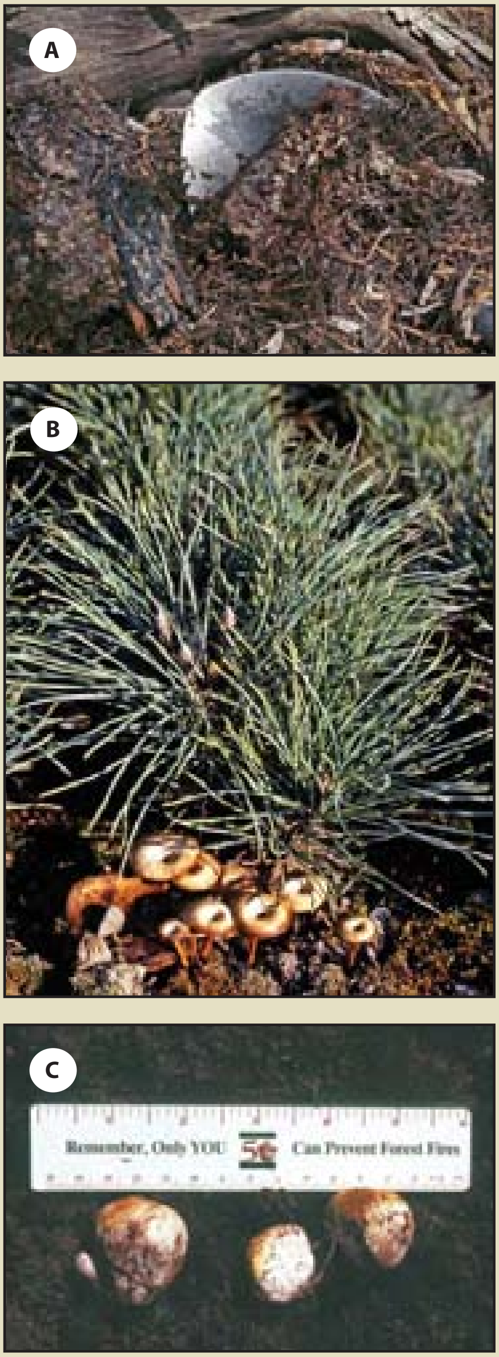
- ***Ectomycorrhizal fungi (ECM)*** have relatively narrow host ranges and form partnerships with many temperate forest plants, especially pines, oaks, beeches, spruces, and firs.
- ***Arbuscular mycorrhizal fungi (AMF)*** are also known as endomycorrhizae or vesicular-arbuscular mycorrhizae. These fungi have wide host ranges and are found on most wild and cultivated grasses and annual crops, most tropical plants, and some temperate tree species including cedars, alders, and maples.
- ***Ericoid mycorrhizal fungi*** form partnerships with the Epacridaceae, Empetraceae, and most of the Ericaceae; plants affected include blueberries, cranberries, crowberries, huckleberries, azaleas, rhododendrons, and sedges. Because these mycorrhizal associations involve unique species of fungi, few commercial inoculants are available and the best option is to use soil from around healthy plants.

Figure 10.32 ***– Mycorrhizal fungi offer many benefits to the host plant. The fungal hyphae increase the area of absorption for water and mineral nutrients, whereas fungal mantle covers the root and protects it from desiccation and pathogens (A). In fumigated nursery soils, inoculated seedlings are much larger and healthier than those that lack the fungal partner (B).***

For restoration purposes, the important thing to remember is that different plant species have specific fungal partners. ECM fungi are generally specific to one genus or group of plants whereas the same AMF fungus can colonize a wide variety of species. In addition, the three types of mycorrhizal fungi have to be inoculated differently. ECM species have airborne spores that can reinoculate soils naturally over time, or the spores can be harvested and used to inoculate nursery stock. On the other hand, the spores of AMF species are large and released underground and so cannot reinoculate plants very quickly. This makes artificial inoculation even more critical.

Conserving existing topsoil and organic matter is a key practice to protect existing populations of beneficial microorganisms. If disturbance will take place, then other interventions will be necessary to introduce the key microsymbionts for the plants you are trying to establish. Consider the needs for mycorrhizal inoculants. Are the species to be established endomycorrhizal, ectomycorrhizal, ericoid or non-mycorrhizal? The selection of the mycorrhizal inoculants must be based on the target host plants and the site condition. Conifer seedlings, for example, require very specific ectomycorrhizal fungi for successful inoculation. Endomycorrhizal species, on the other hand, are broad in range and therefore a general mix of several endomycorrhizal species can be utilized for a broader range of plants. Knowing which species you are working with is essential in order to match the plants with their appropriate microsymbiont partners.

***Figure 10.33** – Soil inoculum can be collected from adjacent plants if done carefully (A). Inoculum can also be made from the spores of mushrooms (B), puffballs, or truffles (C) collected from around the proper host plant.*



10.1.7.3 Sources and Application of Ectomycorrhizal Fungi

Three common sources of ECM inoculants are soil, spores, or pure culture vegetative inoculum.

Soil – Topsoil, humus or duff from beneath ECM host plants can be used for inoculum if done properly. Because disturbance and exposure to direct sunlight may kill these beneficial fungi, soil inoculation must be done as quickly as possible. Soil inoculum can also be collected under the same plant species adjacent to the project site (Figure 10.33A). Small amounts should be collected from several different locations and care should be taken not to damage the host plants. If topsoil and organic matter are not available on the project site, spores or commercial inoculants can be used instead.

Spores – Spore suspensions are sometimes available from commercial suppliers. However, the quality of commercial sources can be variable so it is important to verify the quality of the inoculum. It is possible to make your own inoculum from spores. Collect ripe fruiting bodies of mushrooms (Figure 10.33B), puffballs, or truffles (Figure 10.33C) from beneath healthy plants. Then, rinse and pulverize them in a blender for several minutes to make a slurry. Fungal spores do not have a long shelf-life and should be applied immediately.

Pure Culture Inoculum – Mycorrhizal fungi are available commercially as pure cultures, usually in a peat-based carrier (Figure 10.34). Most commercial sources contain several different species of ECM. Because this type of inoculum is made from pure fungal cultures and does not store well, it is rarely available from suppliers.

Application rates and methods for ectomycorrhizal inoculums will vary by species. Since these mycorrhizal fungi are very specific to their host species, it is important to work closely with company representatives when using ectomycorrhizal inoculum. Nurseries may inoculate plants; if this service is desired, it must be stated in the seedling-growing contract. Some ectomycorrhizal fungi products can be incorporated into the nursery growing media prior to sowing (Figure 10.34A) or a liquid slurry of fungal spores can be applied during the growing season. However, there is no guarantee that the plants will still be colonized when they are planted at the project site.

Other ectomycorrhizal fungal inoculums are applied at the time of planting and here the objective is to get the inoculum in contact with the plant roots. Some formulations are mixed with water and the slurry is applied to the roots of nursery stock. Tablets or packets can be placed in the planting hole (Figure 10.34B). However, the effectiveness of many of these applications has not been verified by research under roadside revegetation conditions.

Verifying the Effectiveness of ECM Inoculation – Luckily, it is fairly easy to recognize ECM as the fungi can be seen with the naked eye on the root system. Short feeder roots should be examined for a cottony-white appearance on the roots or a white or brightly colored mantle or sheath over the roots (Figure 10.35). Unlike pathogenic fungi, mycorrhizae will never show signs of root decay and the mycelia around the root will be visible. Sometimes, mushrooms or other fruiting bodies will occasionally appear alongside their host plants. For verification, it is recommended that plant samples be sent to a laboratory where they can also provide a numerical rating of inoculation effectiveness.

10.1.7.4 Sources and Application of Arbuscular Mycorrhizal Fungi

The two main sources of AMF inoculants include "pot culture," (also known as "crude" inoculant), and commercially available pure cultures.

Figure 10.34 – *Commercial sources of ectomycorrhizal inoculum are available in several forms: pure cultures grown on peat moss or vermiculite (A) are perishable but spore-based products can be applied as root dips. Tablets and packets are put in the hole during planting.*

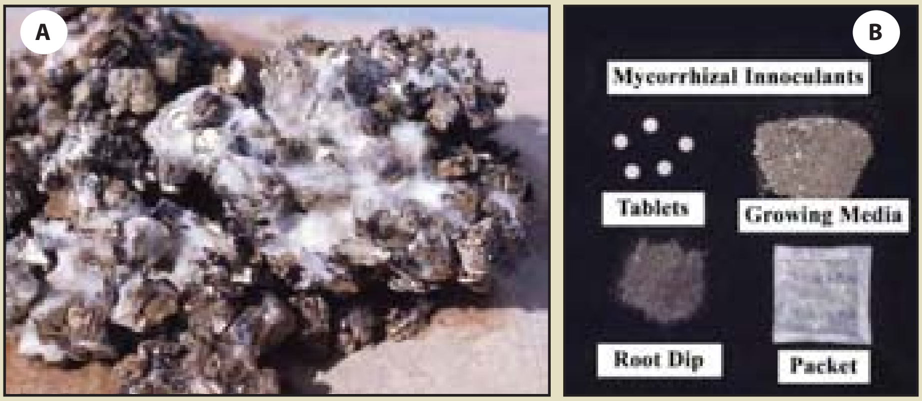


Figure 10.35 **–** *Ectomycorrhizae are visible on plant root systems as white or colored structures with a cottony or felt-like texture.*

Nursery Pot Culture – This option is only viable in a nursery when plants are being grown for a specific restoration project, and is unique to AMF fungi because of their wide host range. A specific AMF is acquired either commercially or from a field site as a starter culture, and then added to a sterile potting medium. A host plant such as corn, sorghum, clover, or an herbaceous native plant is then grown in this substrate; as the host grows, the AMF multiply in the growing medium (Figure 10.36A). The shoots of host plants are removed and the substrate, now rich in roots, spores, and mycelium, is chopped up (Figure 10.36B). The resultant inoculum can then be incorporated into growing media or planting beds before seeds or cuttings are sown. This is a highly effective technique for propagating AMF in the nursery and could also be used on the planting site. For details refer to *Arbuscular Mycorrhizas: Producing and Applying Arbuscular Mycorrhizal Inoculum* (Habte and Osorio 2001).

Commercial Products – Several brands of commercial AMF inoculants are available, and usually contain a mix of several fungal species. Because AMF spores are so small and fragile, they are mixed with a carrier such as vermiculite or calcined clay to aid in application. Coarser textured products (Figure 10.37A) are meant for incorporation into soil or growing media, and finer-textured products (Figure 10.37B) are applied as wettable powders through sprayers or injected into irrigation systems. Inoculation effectiveness has been shown to vary considerably between different products (Figure 10.37C), so it is wise to install tests before purchasing large quantities of a specific product. Laboratories can provide a live spore count which is the best measure of inoculum quality.

Application of AMF Inoculants – Because AMF spores are relatively large, ensuring that spores come in direct contact with the root systems or seeds is critical. Spores will not easily pass through irrigation injectors or nozzles, and do not move downward or through the soil into the soil with water. Therefore, applying AMF inoculum as a topdressing is not a good option. AMF

Figure 10.36 **–** *Because of their wide host range, AMF fungi can be raised on host plants (A) and their roots chopped-up for inoculum (B).*

inoculums typically come in a granular form with different grades of fineness. Coarse grade products (Figure 10.37A) are mixed in the soil prior to sowing seed. Finer grade inoculums (Figure 10.37B), which are more expensive, may be mixed with water and applied directly onto seeds or as a root dip. Use of fine-grade inoculum through hydroseeding equipment is a recent application method that shows promise as a way to combine AMF with seeds as they are sown. Again, there is little research on AMF inoculation effectiveness on roadside revegetation sites.

Verifying the Effectiveness of AMF Inoculation – Unlike ECM, AMF are not visible to the unaided eye. To verify the effectiveness of AMF inoculation, roots must be stained and examined under a microscope (Figure 10.37D). This verification can often be done easily and inexpensively in a laboratory.

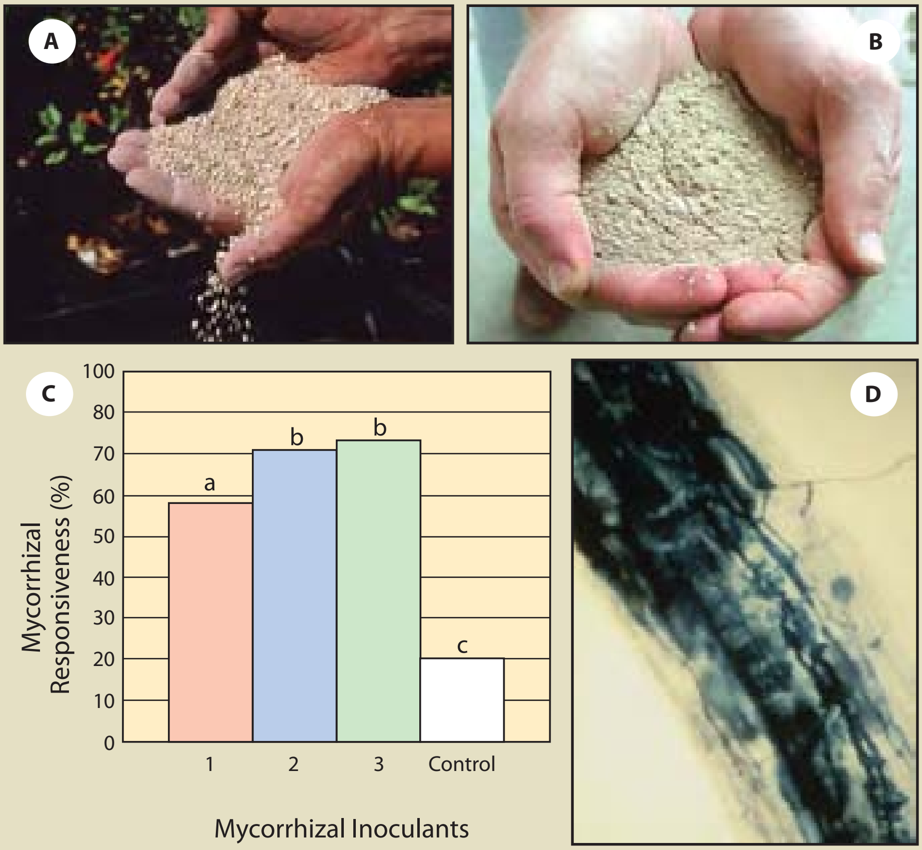
10.1.7.5 Management Considerations for Mycorrhizal Fungi

If possible, work with a specialist to help with the following:

- Selecting appropriate mycorrhizal partners for the species and outplanting sites;
- Determining the best sources of inoculant and evaluating their effectiveness in the field conditions; and
- Designing outplanting trials to evaluate seedling survival and mycorrhizal performance in the field, and modifying the inoculant sources if improvements are needed.

In addition to learning how to effectively apply mycorrhizal fungi, some soil management modifications will be required to promote formation of mycorrhizal partnerships in the field.

Figure 10.37 – *Several commercial AMF inoculums are available and consist of fungal spores mixed with an inert carrier to aid in application. Coarser-textured products (A) can be incorporated into soil or growing media, whereas finer-textured products can be sprayed like a wettable powder (B). Tests of inoculation effectiveness have shown significant differences between products (C). To confirm inoculation, plant roots must be stained so that the fungal hyphae are visible under a microscope (D). C modified from Corkidi and others (2005).*



Fertilization is probably the most significant adjustment. Mycorrhizal fungi extend the plant's root system, and extract nutrients and water from the soil. High levels of soluble fertilizers may inhibit their presence. In some cases, fertilizer applications can be reduced by half or more due to the increased nutrient uptake by mycorrhizal fungi. Fertilizer type and form is also important. An excessive amount of phosphorus in the fertilizer inhibits formation of the partnership; therefore phosphorus should be reduced. If nitrogen is applied, ammonium-N is better used by the plant than nitrate-N (Landis 1989). Controlled release fertilizers are preferred because they release small doses of nutrients gradually, compared to the more rapid nutrient release from traditional products. Applications of certain herbicides, pesticides, insecticides, fungicides, and nematicides are detrimental to mycorrhizal fungi.

10.1.7.6 Nitrogen-Fixing Bacteria

Nitrogen-fixing bacteria live in nodules on plant roots and accumulate ("fix") nitrogen from the air and share it with their host plants. Unlike mycorrhizal fungi, which are found on most trees and plants, only certain species of plants can form symbiotic partnerships with nitrogen-fixing bacteria.

The role of nitrogen-fixing bacteria and their partner plants is crucial to roadside restoration. Because nitrogen-fixing plants are often "pioneer" species that are the first to colonize disturbed sites, they are ideal for revegetation or restoration projects. Nitrogen-fixing species are usually outplanted in order to help restore fertility and organic matter to the project site. Nitrogen-fixing bacteria form nodules on roots of certain plants (Figure 10.38A) and accumulate nitrogen from the air (Figure 10.38B). While plants that form this association are sometimes called "nitrogen-fixing plants", the plant itself is not able to fix nitrogen from the air. It is only through the partnership with bacteria that these plants are able to obtain atmospheric nitrogen. In this symbiotic partnership the bacteria give nitrogen accumulated from the atmosphere to the plant, and in exchange the bacteria get a site to grow and energy in the form of carbohydrates from the plant. Without these bacterial partnerships, plants are not able to make direct use of atmospheric nitrogen.

Soil on restoration sites, however, may not contain the proper species of bacteria to form a symbiotic partnership with the plant. This is particularly true for compacted soils and those that have been removed and stockpiled. Inoculating plants ensures that "nitrogen-fixing"

Figure 10.38 – *Nitrogen-fixing plants, such as legumes, have symbiotic bacteria on their roots (A) which can chemically "fix" atmospheric nitrogen into forms that can be used by plants as fertilizer (B).*

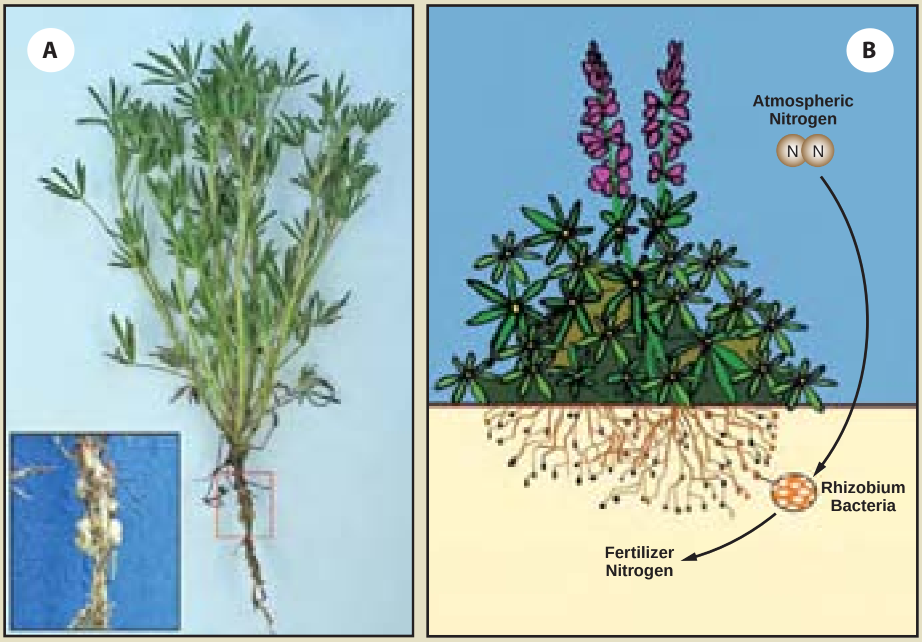


Figure 10.39 – *Nitrogen-fixing bacteria include Rhizobium that forms relationships with plants in the legume family including lupines (A), and clovers (B) and Frankia that forms relationships with other non-leguminous plants such as snowbrush ceanothus (C), and mountain-avens (D) . Photos A, C, & D by Tara Luna.*

plants form an effective partnership to fix nitrogen. Therefore, use of nitrogen-fixing plants can be an important part of accelerating rehabilitation of degraded land.

Two species of nitrogen-fixing bacteria that are important in revegetation are *Rhizobium* and *Frankia*. *Rhizobium* grow with some members of the legume family (Figure 10.39 A&B), and plants of the elm family. They form nodules on the roots and fixing nitrogen for the plant. *Frankia* are

Table 10.11 – *Nitrogen-fixing bacteria and their plant hosts.*

Nitrogen-Fixing Bacteria	Host Plants		% Nitrogen Fixing Plants	Common Plant Species
	Family	Subfamily		
Rhizobium spp.	Legume	Caesalpinioideae	23	Redbud, honeylocust
	Legume	Mimosoideae	90	Mesquite, acacia
	Legume	Papilionoideae	97	Lupine, milkvetch, black locust, clover
	Family		**Common Plant Species**	
Frankia spp.	Birch		Alder, birch	
	Oleaster		Silverberry, buffaloberry	
	Myrtle		Myrtle	
	Buckthorn		Cascara, snowbrush, deerbrush	
	Rose		Mountain mahogany, cliffrose, bitterbrush	

Inset 10.9 – Example of Contract Specifications for Purchasing Mycorrhizal Inoculum

Purchase of Mycorrhizal Inoculum

The mycorrhizal inoculum must have a Statement of Claims that certifies the 1) date inoculum was produced, 2) mycorrhizal fungi species present in the inoculum, 3) number of propagules per pound of product, and 4) the type and grade of carrier.

Product Specifications

Date of inoculum application will be within one year of production date.

The storage, transportation and application temperatures of the mycorrhizae shall not exceed 90 °F. Inoculum must consist of at least 5 species of (choose endomycorrhizal, ectomycorrhizal or a combination of endo and ectomycorrhizal) fungi with no one species making up more than 25% of the propagules.

The inoculum will contain these species: __________________.

The inoculum will contain __________ live propagules per pound (Typical rates for endomycorrhizal inoculums average around 60,000 to 100,000 propagules per pound and 110,000,000 propagules per pound in ectomycorrhizal inoculums.)

(For applications to the soil surface only) Live propagules must be smaller than 0.3mm.

(Optional) A one ounce sample will be collected from each inoculum and sent to _______ laboratory for analysis using the ______ standardized test to determine the number of propagules.

Application of Endomycorrhizal Inoculum to Soil Surface

Endomycorrhizal inoculum will be applied at a rate of __________________ live propagules per acre (typical rates range from 1,000,000 to 3,600,00 live propagules per acre).

Inoculum will be applied in the same operational period as seed application.

If inoculum is applied through a hydroseeder, it should be applied within 45 minutes of being mixed in the hydroseeding tank.

Application of Mycorrhizal Fungi to Planting Holes

Mycorrhizal inoculum will be applied at a rate of ______________ live propagules per seedling.

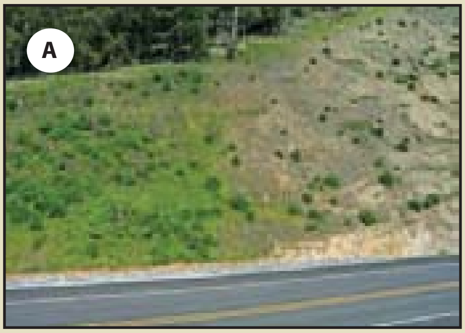
a different kind of bacteria. *Frankia* partner with non-leguminous plants, such as casuarinas, alders, bitterbrush, and buffaloberry (Figure 10.39 C&D), and over 200 different plant species, distributed over eight families. The species affected by *Frankia* are called "actinorhizal" plants (Table 10.11).

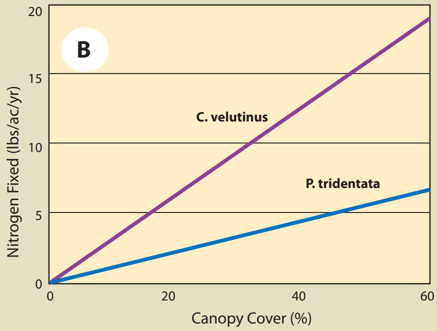
10.1.7.7 Uses for Nitrogen-Fixing Plants in Revegetation

Only a fraction of native species are nitrogen-fixing host plants. In the western United States, the most common are the lupines, vetch, bitterbrush, ceanothus, alder, and myrtle (Table 10.11). On nitrogen-poor sites, sowing or planting a higher proportion of these species can help a site to recover nitrogen fertility and organic matter (Figure 10.40A). The amount of nitrogen that will be fixed on a site is related to the area of vegetative cover in nitrogen fixing host plants, the productivity of the plants, and factors such as temperature and moisture. If percent cover of nitrogen fixing host plants is low, then the amount of nitrogen supplied to the site will be correspondingly low (Figure 10.40B). Likewise, dry or cold conditions tend to result in slower accumulation of nitrogen.

To determine how nitrogen-fixing plants should be used in revegetation project, assess which nitrogen-fixing host species are native to the area and consider the nitrogen fixation rates that can be expected. A plant survey of reference sites will reveal which nitrogen fixing plant host species are native to the area. Finding host plants on recovered reference sites can give an indication of whether they grow on disturbances, and consequently how much nitrogen will be fixed on the site. Observing the abundance of root nodules on these plants can give some indication whether they are fixing nitrogen.

__Figure 10.40 –__ The accumulation of nitrogen by N-fixating bacteria is directly related to the cover of nitrogen-fixing host plants on a site. The large plants shown in this photograph are lupines, which are nitrogen-fixing (A). The nitrogen-fixing potential of 15-year-old stands of Ceanothus velutinus *and* Purshia tridentata *was directly proportional to plant cover (B) (adapted after Busse 2000).*





10.1.7.8 Inoculating with Nitrogen-Fixing Bacteria

Nitrogen-fixing nursery stock with nodulated root systems have exhibited faster early growth than seedlings that were not inoculated. Nursery inoculation can reduce costs in establishment and maintenance; a few dollars worth of inoculant applied in the nursery can replace a lot of purchased nitrogen fertilizer over the life of the nitrogen-fixing plant. Faster growth early can also lead to faster canopy closure, which shades the soil and reduces weed establishment and growth. When the nitrogen-fixing plant sheds leaves or dies, the nitrogen stored in the plant's tissues is cycled to adjacent plants. Early establishment of nitrogen-fixing plants accelerates natural nutrient cycling on the project sites and promotes the establishment of sustainable plant communities.

It should be noted that in many cases, uninoculated seedlings may eventually form a partnership with some kind of *Frankia* or *Rhizobium* strain after they are outplanted. These may not be with optimal or highly productive bacterial partners, and it may take months or even years on highly disturbed sites. Until they become naturally inoculated, plants are dependent on nitrogen fertilizers and may become out-competed by weeds. Inoculating in the nursery ensures that plants form effective, productive partnerships in a timely fashion.

Acquiring Nitrogen-Fixing Bacterial Inoculants – Nitrogen-fixing bacteria are very specific; in other words, one inoculant cannot be used for all plants. On the contrary, a different inoculant strain for each nitrogen-fixing species is usually necessary. Superior strains can yield significant differences in productivity and growth rate of the host plant; in some cases over 40% better growth (Schmit, 2003).

Inoculants are live nitrogen-fixing bacteria cultures that are applied to seeds or young plants. Two forms of inoculant can be used: pure culture inoculant, and homemade (often called "crude") inoculant. Cultured inoculant is purchased from commercial suppliers, seed banks, or sometimes, universities. Crude inoculant is made from nodules collected from roots of nitrogen-fixing plants of the same species to be inoculated. Whichever form is used, care should be taken when handling nitrogen-fixing bacteria inoculants because they are very perishable. These soil bacteria live underground in moist, dark conditions with relatively stable, cool temperatures. Similar conditions should be maintained to ensure the viability of inoculants during storage, handling, and application.

Pure culture inoculants of nitrogen-fixing bacteria usually come in small packets of finely ground peat moss (Figure 10.41A). Some manufactured inoculants contain select strains, tested for forming optimally productive partnerships with their host species. Select inoculant should be used if it can be obtained; these contain optimal partners for the species they were matched for, providing a good supply of nitrogen at a low cost to the plant. Manufactured products usually come with application instructions; these should be followed. In general, about 100 grams of cultured inoculant is usually sufficient to inoculate up to 3,000 seedlings in nursery conditions. Because they contain living cultures of bacteria, these inoculants are perishable and should be kept in cool, dark conditions, such as inside a refrigerator.

Figure 10.41 – *Nitrogen-fixing bacteria are commercially available as pure culture inoculant, often in a carrier (A), or can be prepared by collecting nodules off of plants from the wild (B). Photos by Tara Luna.*

Peat-based inoculants are added to chlorine-free water to create a liquid slurry (Allowing a bucket of tap water to stand uncovered for 24 hours is a good way to let chlorine evaporate). If a blender is available, using it to blend some inoculant in water is a very good practice to ensure the bacteria will be evenly mixed in the solution. If a blender is not available, a mortar can be used. Five to ten grams (about 0.2–0.4 ounce) of manufactured inoculant can inoculate about 500 seedlings, usually exceeding the recommended 100,000 bacteria per seedling. Once seedlings begin to nodulate, nodules from their roots can serve as the basis for making crude inoculant as described below. This way, inoculant need only be purchased once for each plant species grown, and thereafter, crude inoculant can be made from nodules.

Preparing Crude Inoculant – Crude inoculant is made using nodules, the small root structures that house the bacteria. Each one of the nodules can house millions of bacteria. For *Rhizobium*, a brown, pink, or red color inside is usually a good indicator that the millions of bacteria in the nodule are actively fixing nitrogen. For *Frankia*, desirable nodules will be white or yellow inside. Grey or green nodules should be avoided, as they are likely inactive.

To make your own crude inoculant, select healthy, vigorous plants of the same species as the plants to be inoculated. Expose some of the root system of a nodulating plant in the nursery or field (Figure 10.41B). If available, choose seedlings that were inoculated with select bacteria. Young roots often contain the most active nodules. Search for nodules with the proper color and pick them off cleanly. If possible, collect nodules from several plants. Put nodules in a plastic bag or container and place them in a cooler for protection from direct sunlight and heat. As soon as possible after collection (within a few hours), put the nodules in a blender with clean, chlorine-free water. About 50-100 nodules blended in a liter of water is enough to inoculate about 500 seedlings. This solution is a homemade liquid inoculant, ready to apply in the same method as cultured inoculant as described below.

Applying Inoculant – Inoculant must be applied in a timely fashion, when seedlings are just emerging, usually within 2 weeks of sowing. This helps ensure successful nodulation and

Figure 10.42 – *After successful inoculation, nitrogen-fixing bacteria will multiply on the root system as plants grow. The arrow points to a visible* Frankia *nodule on an* alnus *seedling. Photo by Tara Luna.*

maximizes the benefits of using inoculants. Therefore inoculant must be introduced in the nursery for nursery-grown plant materials, or introduced at the time of sowing for seeds that are sown directly at the field site. One liter of liquefied inoculant made from either nodules or cultured inoculant as per the instructions above is diluted in more chlorine-free water. For 500 seedlings, about 5 liters of water is used. This solution is then watered into the root system of each seedling using a watering can. In the field, for direct seeding applications, the slurry of commercial or crude inoculant can be added to the hydroseeder tank and mixed in with seed mixes.

Inset 10.10 – How Does Biological Nitrogen Fixation Work?

The symbiotic partnership between plants and their nitrogen-fixing microsymbionts works this way: The bacteria live in nodules on roots of the plant. Each nodule contains millions of the bacteria that accumulate atmospheric nitrogen and share this nitrogen with the plant. In exchange, the plant provides energy in the form of carbohydrates to the bacteria.

The bacteria must come in contact with the root systems early in the plant's life, ideally within the first 2 to 6 weeks of growth. For nursery-grown materials, nitrogen-fixing bacteria must be introduced in the nursery. For direct field sowing of seed, inoculants should be applied as the seeds are being sown.

When the "nitrogen-fixing" plant sheds its leaves, dies, or dies back, the nitrogen stored in the plant's tissues is cycled to other plants and through the ecosystem. This process, part of the nitrogen cycle, is the major source of nitrogen fertility in most natural ecosystems.

10.1.7.9 Management Considerations for Nitrogen-Fixing Inoculations

Verifying the Nitrogen-Fixing Partnership – Allow two to six weeks for noticeable signs that the plant has formed a symbiotic partnership with nitrogen-fixing bacteria. Signs include:

- Seedlings begin to grow well and are deep green despite the absence of added nitrogen fertilizer,
- The root systems give off a faint but distinctive ammonia-like scent,
- Nodules are usually visible on the root system after about four to six weeks (Figure 10.42), and nodules are pink, red, or brown (for *Rhizobium*), or yellow or white (for *Frankia*).

Post-Planting Care – Several factors are of primary concern when using inoculants for nitrogen-fixing bacteria:

- ***Fertilization.*** The use of nitrogen-fixing bacterial inoculant requires some adjustments in fertilization. Excessive nitrogen fertilizer will inhibit formation of the partnership.
- ***Water quality.*** Excessive chlorine in water is detrimental to Rhizobium and Frankia. The water source may need to be tested and a chlorine filter used if excessive chlorine is a problem.
- ***Micronutrients and soil quality.*** Some nutrients are necessary to facilitate nodulation, including calcium, potassium, molybdenum, and iron. Excessively compacted soils, extremes of pH or temperature also inhibit nodulation.

10.1.7.10 Other Beneficial Microorganisms

In nature, communities of bacteria, fungi, algae, protozoa, and other microorganisms in the soil make nutrients available to plants, create channels for water and air, maintain soil structure, and cycle nutrients and organic matter. A healthy population of soil microorganisms can also maintain ecological balance, preventing the onset of major problems from viruses or other pathogens that reside in the soil. The practice of protecting and re-establishing beneficial microorganisms is a key one for revegetation. As a science, however, the use of beneficial microorganisms is in its infancy. Although thousands of species of microorganisms have been recognized and named, the number of unknown species is estimated to be in the millions. Almost every time microbiologists examine a soil sample, they discover a previously unknown species (Margulis and others, 1997). Revegetation specialists should keep an eye on developments in this field and see how their plants can benefit from new insights into the roles of microorganisms. Conserving and utilizing healthy topsoil will also help to sustain the natural populations of beneficial microorganisms.

10.1.8 TOPOGRAPHIC ENHANCEMENTS

10.1.8.1 Introduction

Topographic enhancements are alterations to the roadside landscape designed to improve the growing environment for plants. Topographic enhancements should be considered when site resources such as topsoil, organic matter, and water are limited (See Section 5.11, Inventory Site Resources). It is often better to concentrate limited resources in key areas where resources can be most effective, rather than spread them across the larger project area and dilute them to the point of having little benefit to reestablishing native vegetation.

Topographic enhancement integrates three components into the roadside design – soil improvement, site stability, and water harvesting (Figure 10.43). Soil improvement can occur when limited topsoil and organic matter are strategically used to create growing areas with optimum rooting depth (See Section 5.3 and Section 5.5). Stable landforms are created that reduce surface erosion and increase slope stability (See Section 5.6 and Section 5.7). Water harvesting can result when local topography is modified to capture runoff water and concentrate it in areas where it can be used by plants (See Section 5.2) (For background on water harvesting, see Fidelibus and Bainbridge 2006).The integration of these three components will determine the success of a topographic enhancement design.

Topographic enhancement strategies must be considered during the initial planning stages of road design. These structures will require the input of the design engineer and cooperation of the project engineer, and must be built during the construction phase of the project. Structural changes to the topography following construction are not usually an option for revegetation purposes.

There are many options for topographic enhancement. This discussion is by no means exhaustive, but intended to introduce the reader to a variety of structures that can be installed during road construction to enhance the establishment of native plants.

10.1.8.2 Contour Bench Terraces, Planting Pockets, and Microcatchments

Contour bench terraces are structures carved out of cut or fill slopes that capture and store runoff water and sediments from road surfaces, road shoulders, and the slopes above. If infiltration rates of soils above the terraces are low, runoff will occur, even from low intensity rainfall. Contour bench terraces are designed to collect enough water to recharge soils and provide sufficient water for plant growth during the summer, but also be protected from erosion during peak rainstorm events. Design criteria for determining the distance between terraces include slope gradient, rainfall intensities, and infiltration rates. Observing erosional patterns on unvegetated road cuts near the project site can give an indication of approximate spacing for benches (See Section 5.6.8).

Contour bench terraces can be long and contiguous or separate and discrete. For long and contiguous terraces, concentrated water from high runoff events can flow down the terraces (assuming they are not completely level), potentially causing gullies. Placing berms or "plugs" in the terraces at frequent intervals can reduce this potential.

When terraces are filled with growing media (topsoil or amended subsoil) and planted, they are referred to as planting pockets (Figure 10.44). Planting pockets must have adequate soil depth to store intercepted water and support establishment of planted seedlings. The surface of the planting

***Figure 10.43** – Integrating soil improvement, site stability, and water harvesting is critical when designing topographic enhancement features.*

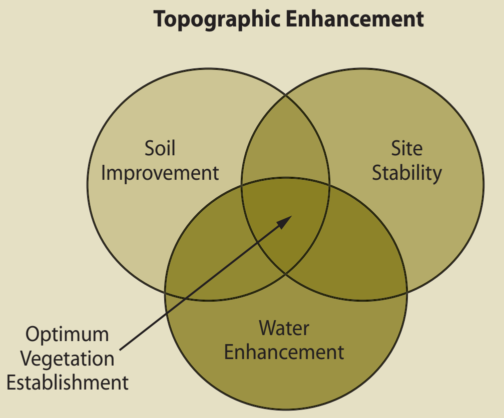
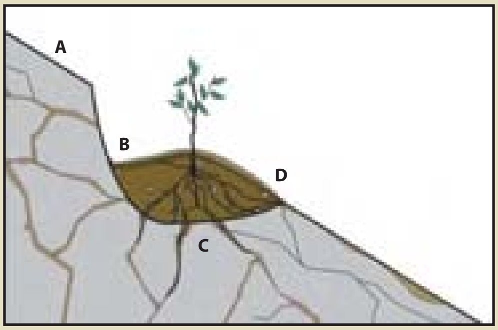


__Figure 10.44 –__ Planting pockets collect and store runoff water from areas directly upslope during rainstorms (A). Water and sediments collect in the back slope of the pocket (B). Moisture fills the soil and moves into fractured bedrock (C) where roots have penetrated. The face of the planting pocket is protected by mulch or erosion cloth (D). The photograph on the right was taken looking down on a planting pocket after a rainstorm. The back slope has ponded water and collected sediments from the surface above.



pocket should be insloped to capture water and sediment, and the face of the pocket should be protected from surface erosion.

Fill slope microcatchments are structures that capture runoff from outsloped road surfaces and compacted shoulders into terraces and berms where it can be used for plant growth (Figure 10.45). Microcatchments include a storage basin and berm. Berms are typically 4- to 8-inch high obstacles placed on the contour. They are formed from soil or woody debris (logs), or manufactured products such as straw waddles (Figure 10.45) or compost berms. Manufactured products and woody debris are "keyed" (partially buried) into the soil surface to prevent water from eroding under the structure. Compost berms are continuous mounds of compost that can slow water and filter sediments. Seedlings can be planted on, or immediately above, berms or obstacles to access captured water. Unless species that propagate vegetatively are used in these structures (See Section 10.2.2), care must be taken to avoid planting where sediment will bury the seedling. The storage basin, created by terraces or berms, can be improved for plant growth with soil tillage and incorporation of soil amendments.

__Figure 10.45 –__ Fill slope microcatchments take advantage of the low infiltration rates of compacted fill slopes (A) by capturing the runoff from road drainage at the bottom of the fill into topsoil or amended subsoil favorable for plant growth (B). The extra water from these surfaces can support trees and shrubs. Straw waddles, as shown in the picture on the right, can be used in fill slope microcatchments to collect water and sediment. Straw waddles must be installed on the contour and keyed into the soil to be effective.

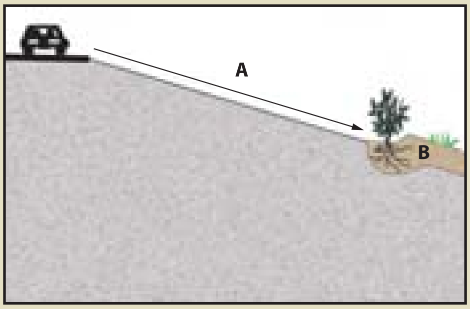


Figure 10.46 – *Constructed wetlands capture water from roadside runoff and filter sediments before water enters perennial streams. Constructed wetlands can create favorable habitat for unique flora and fauna.*

10.1.8.3 Runoff Strips and Constructed Wetlands

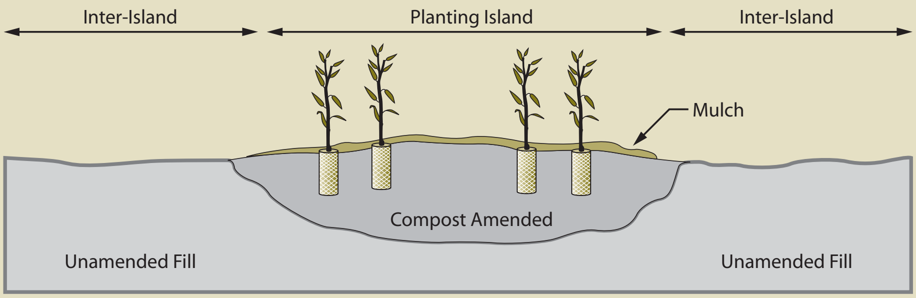
Runoff strips are catchment structures constructed in areas where intermittent concentrated road drainage occurs. These are typically at the outlets of culverts or in road drainage dips. Runoff strips capture concentrated runoff into small ponds or catchment basins. These areas can be planted with riparian species, such as willows (*Salix* spp).and cottonwoods (*Populus* spp.), or wetland species, such as rushes (*Juncus* spp).and sedges (*Carex* spp.). Runoff strips are placed in draws or concave topography and are composed of engineered impoundment barriers, using riprap, logs, or gabion baskets, that store water from runoff events. The barrier must have a spillway (a low point in the structure) and be keyed into the sides to assure that concentrated water does not erode around its sides. Where runoff strips are on gentle gradients, constructed wetlands may possibly be developed (Figure 10.46).

10.1.8.4 Planting Islands

Planting islands are used where deep-rooted tree and shrub species are desired, but topsoil, soil amendments, or soil depth are limiting. They are designed into such revegetation projects as obliterated roads, view corridors, waste areas, and other highly disturbed sites. The strategy behind planting islands is to create an ideal growing environment for tree and shrub seedlings that replicates the natural patterns or features observed in the surrounding landscape and plant communities (Figure 10.47).

Figure 10.47 – *Most planting islands are designed to mimic the natural surrounding environment of the project site. In this photograph, seedlings were planted in clumps to mimic the small islands of trees that grew in this geographic area. The inter-island areas were planted with lower growing grasses, forbs, and shrubs.*

***Figure 10.48** – Illustration of a typical cross-section of a planting island where soil depth is enhanced for tree establishment. Inter-island areas are planted to shrubs and grasses.*



Islands can be created by excavating an appropriate area to a depth of several feet and backfilling with either topsoil or compost-amended material (Figure 10.48). Alternatively, compost and other soil amendments (including lime and fertilizers) can be spread over planting islands at the depth needed to amend the soil profile and mixed thoroughly through the islands with an excavator or backhoe. Soil compaction must be avoided in these operations or during any subsequent operation. After planting, mulch can be applied across the surface of the entire island.

In Figure 10.48, compost is mixed to a depth of 3 feet by an excavator in irregular shaped planting islands. The islands are planted with conifers and 3 inches of mulch are applied to entire islands to keep them free of competing vegetation. The layout of planting islands should be designed with a vision of how the vegetation will appear once established, and should be based on recovered and undisturbed reference sites. Planting islands will generally occupy less than a quarter to a third of the entire site, leaving the remainder as "inter-island." The inter-islands will be much less productive than the planting islands. Grass and forb plant communities are therefore more suited to these areas.

10.1.8.5 Biotechnical Engineering Structures

Topographic enhancement also includes many biotechnical engineering structures, such as vegetated retaining walls, brush layers, and live pole drains. Incorporating soil improvement strategies into these structures will stabilize the soil and capture runoff water, making them very suitable to the establishment of a range of native vegetation (See Section 10.3.3 and Section 10.3.4).

10.2 OBTAINING PLANT MATERIALS

Obtaining the appropriate species and stocktype for a revegetation project takes good planning and lead time. To obtain genetically adapted materials often requires the collection of plant materials near or in the general geographic area of the project site. This requires collecting plant materials several years in advance of project implementation. The group of implementation guides in the following section focuses on three types of plant materials – seeds, cuttings, and plants. Section 10.2.1, Collecting Wild Seeds, covers how to determine the amount of wild seed to collect, wild seed collection methods, cleaning techniques, storage conditions, and quality testing. Methods for collecting the stems of willows and cottonwoods in the wild (as well as several other native species that propagate vegetatively) are discussed in Section 10.2.2, Collecting Wild Cuttings. Salvaging plants from the wild and replanting them on project sites is discussed in Section 10.2.3, Collecting Wild Plants.

For most projects, the collection of wild seeds, cuttings, or plants is not sufficient to meet project objectives. To increase plant materials, wild collections must be sent to native plant nurseries for propagation. Section 10.2.4, Nursery Seed Production, outlines the basic steps necessary to work with nurseries in establishing seed production beds for increasing seed banks. Producing large quantities of cutting material of willow and cottonwood species can be accomplished by establishing stooling beds from wild collections at nurseries. This is covered in Section 10.2.5, Nursery Cutting Production. Section 10.2.6, Nursery Plant Production, covers how to work with seedling nurseries to obtain high quality plants.

10.2.1 COLLECTING WILD SEEDS

10.2.1.1 Introduction

Wild seeds are collected from native stands of grasses, forbs, shrubs, trees, and wetland plants found in or near project sites. The primary objective for wild seed collection is to obtain source-identified seeds for starting nursery grown plants (See Section 10.2.6), nursery grown seeds (See Section 10.2.4), and/or occasionally to sow directly on a disturbed site. Since seed and seedling propagation hinges on availability of wild seeds, collection is one of the first major tasks of a revegetation plan. Depending on the purpose, the lead-time for collecting wild seeds might be up to 3 to 4 years before sowing or planting the project site (Figure 10.49).

Grass and forb species are usually seeded directly onto disturbed sites. In order to obtain enough seeds for direct seeding, wild seed collections are usually "increased" in nursery production (See Section 10.2.4). Trees and shrubs, on the other hand, are not typically seeded across disturbed sites. Wild seed collections for these species are sent to nurseries for seedling propagation, then outplanted. Seeds from wetland genera, such as sedges (*Carex* spp).and rushes (*Juncus* spp).are often collected for both seed and seedling production purposes.

Revegetation plans are seldom finalized before wild seeds are collected. At a minimum, planning should have identified revegetation units, described reference areas, determined species to propagate, and completed a survey of the construction site to determine the amount of area to be revegetated. The quantity and location of wild seed collection is based on these early surveys.

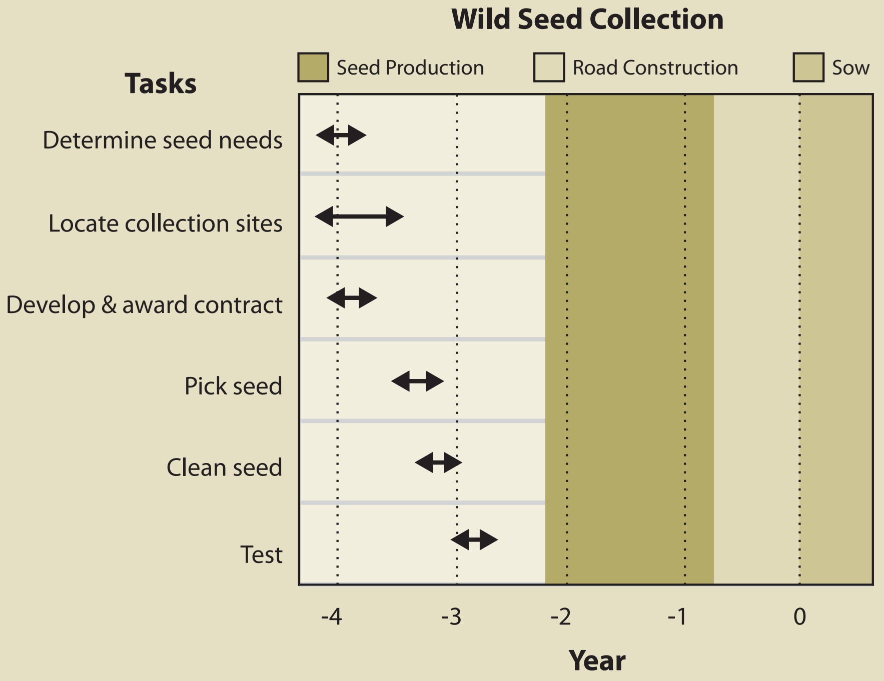
Collecting wild seeds can be expensive. Multiple collection trips are often needed to monitor and collect each species. Each species has a small ripening window, and most species do not ripen at the same time. In addition, many species do not consistently produce seeds from year to year, requiring multiple year collections. Working around these complexities to obtain adequate supplies of wild seeds requires excellent planning and administration of seed collection and cleaning contracts.

Before collecting wild seeds or setting up collection contracts, it is worth the effort to contact Forest Service district or BLM area offices first to see if seeds are already available for your project. Often these local agencies will have seeds in storage for many of the species growing near the project area, especially species used for reforestation.

10.2.1.2 Develop Timeline

Wild seed collection should be one of the first tasks to consider when beginning revegetation planning because other tasks, such as seed and seedling propagation contracts, cannot be conducted without this plant material. Up to 3 or 4 years are often necessary in order to locate,

Figure 10.49 – Wild seed collection is one of the first contracts developed during planning. Seeds are needed to implement seed and seedling propagation contracts. A lead-time of 2 to 4 years is typically needed for wild seed collection.



collect, clean, and test wild seeds, and still allow the nursery or seed producer enough lead time for plant and seed production (Figure 10.49).

The seed collection contract is awarded early in the spring to give the contractor enough time to locate and assess the collection areas. Seeds are monitored from June through August and collected when ripe. Wild seed harvests are cleaned from September through October and then tested. Results from seed testing facilities are returned by December. Seeds designated for seedling propagation must be sent immediately to the nursery for preparation for sowing in early winter. If seed propagation is the objective, seeds are stored until the following summer and sent to seed producers for a late summer sowing.

10.2.1.3 Determine Wild Seed Needs for Seed Production

Wild seed collection and the nursery seed increase contracts are often developed simultaneously because the information needed for wild seed collection is based on the expected seed yields of the seed increase contract. This section describes how to calculate the amount of wild seeds to collect based on the amount of seeds expected from a nursery seed producer.

The amount of uncleaned wild seeds to collect for seed propagation contracts requires the following information (used in calculations in Figure 10.50):

- Seed needs,
- Years in seed production,
- Sowing rates,
- Annual seed yields, and
- "Cleaned-to-rough cleaned" seed ratio.

Seed Needs – The total seeds needed for each species on a revegetation project is based on the total planned revegetation acreage, seedlot characteristics (germination, purity, seeds per pound), site limitations (how well seeds will survive), and the desired seedling densities after seeds have germinated. The reader is referred to Section 10.2.4.3 for methods to calculate how many seeds are needed for each species in a revegetation project.

***Figure 10.50** – The quantity of wild seeds to collect can be determined from this spreadsheet. Pearly everlasting (*Anaphalis margaritacea*) is used in this example.*

A	Seed production needs	22	lbs	From seed needs plan (See Section 10.2.4.3)
B	Years in production	2	yrs	Seed production can span several years depending on lead time of project.
C	Sowing rates	1	lbs/ac	See Table 10.14 in Section 10.2.4 or discuss with seed producer
D	Annual seed yields	50	lbs/ac/yr	See Table 10.14 in Section 10.2.4. If spanning more than one year, average the expected first and second year yields
E	(A/B) / D	0.22	ac	Area seed producer needs to sow
F	E * C =	0.22	lbs	Cleaned wild seeds that seed producer needs to sow
G	"Cleaned to rough cleaned" seed ratio	33	%	Estimated
H	(100 / G) * F	0.67	lbs	Rough weight of seeds to collect

Years in Seed Production **–** Every species has its own seed production characteristics. For instance, species such as blue wildrye (*Elymus glaucus*) and California brome (*Bromus carinatus*) produce high seed quantities the first and second year, then level off or decline in years three and four. Species such as fescues (*Festuca* spp).and Junegrass (*Koeleria* spp).yield few seeds in the first year, but seed harvest levels increase to full production in the second or third year. For these species, a minimum of two years must be scheduled for seed production. Table 10.14 in Section 10.2.4 shows first- and second-year yields for some commonly produced species.

Since seeds can be stored for many years, seed production does not have to occur all in one year. For projects that have several years lead time, maintaining production fields gives the revegetation specialist more flexibility. By spreading the seed production over several years, the acreage in production and the amount of wild seed to collect can be cut in half. For example, if 800 lb California brome (*Bromus carinatus*) seeds for a revegetation project are needed and there are two production years to produce it in, the amount of seeds to produce per year would be 400 lb. Since half the acreage would be sown, the amount of wild seed to collect would be cut in half, from 10 pounds to 5 pounds.

Sowing Rates **–** All growers require a minimum amount of clean, wild seeds to produce a given quantity of nursery-grown seeds. While these rates differ somewhat between seed producers, general sowing rates for commonly propagated species are shown in Table 10.14 in Section 10.2.4.

Annual Seed Production Yields **–** The amount of seeds that are produced annually varies by species, geographic location of the fields, weather conditions, and experience of the seed producer. Knowing what yields can be expected from seed producers will determine how many acres will be under production and the amount of wild seeds needed to start the crop. Average seed yields for some species are presented in Table 10.14 in Section 10.2.4.

Cleaned-to-Rough Cleaned Seed Ratio **–** Seed collection from the wild will include stems, chaff, and flower parts (Figure 10.51). This material should be cleaned as much as possible by the seed collectors before it is sent to the seed extractory for final cleaning. The amount of non-seed collected can be a substantial part of the wild seed collection weight. "Cleaned to rough cleaned" seed ratios (Table 10.12) can help calculate the extra weight of seeds to collect in the wild to compensate for seed cleaning. Dividing the desired amount of cleaned seeds by this ratio will yield the amount of wild seed that needs to be collected.

***Figure 10.51** – Field collected seeds include stems, chaff, flower parts, and seed attachments. Species such as cutleaf silverpuffs* (Microseris laciniata) *have a low "clean-to-rough" seed ratio and must be sent to a seed extractory for cleaning prior to sending to seed producers.*

10.2.1.4 Determine Seed Needs for Seedling Production

The quantity of wild seeds to collect for propagating seedlings at plant nurseries will be based on an estimate of 1) quantity of seedlings needed, 2) % seed germination, 3) % seed purity, 4) seeds per pound, and 5) nursery factor. An estimate of germination, purity, and seeds per pound can be obtained through published sources, seed inventories, or from seed extractory managers. The nursery factor is a prediction of the percentage of viable seeds that will actually become "shippable" seedlings. Each nursery has developed a set of factors based on culturing experience and practices. Nursery managers should supply nursery factors for each species or information on the amount of seeds to collect to meet the seedling order. Nursery factors are often less than 50%.

Using the following equation, the amount of wild seed to collect can be estimated:

$$\textbf{Wild seed to collect} = \frac{\textbf{quantity of seedlings needed}}{\textbf{(\% germ/100 * \% purity/100 * seeds/pound * nursery factor/100)}}$$

10.2.1.5 Locate Plants in the Wild

Collection areas are located in the field during the vegetation analysis phase (See Section 6.2). General collection locations can be established by the revegetation specialist under the direction of a botanist familiar with the local vegetation. Contracts often require seed collectors

***Table 10.12** – Typical ranges of "cleaned-to-rough cleaned" seed ratios. To obtain the amounts of "rough" seeds to collect, divide the amount of cleaned seeds needed by the "cleaned-to-rough cleaned" ratio. For example, if 5 lb cleaned seeds of prairie Junegrass (*Koeleria macrantha*) are needed, a minimum of 12.5 lb rough cleaned seeds must be collected (5/40*100=12.5) (Chart based on R6 Forest Service seed collections data.)*

Common Name	Scientific name	Cleaned-to-Rough Cleaned Ratio
Bluebunch Wheatgrass	*Pseudoroegneria spicata*	**25 to 33**
Idaho Fescue	*Festuca idahoensis*	**33 to 50**
Prairie Junegrass	*Koelaria macrantha*	**20 to 40**
Squirreltail	*Elymus elymoides*	**20 to 25**
Yarrow	*Achillea* spp.	**20 to 25**
Sandberg Bluegrass	*Poa secunda*	**33 to 40**
Blue Wildrye	*Elymus glaucus*	**50 to 65**

Inset 10.11 – Stages of Grass Seed Maturity

For grasses, the stages of seed ripening can be determined by squeezing a seed between the thumb and forefinger. The stage of seed maturity is broadly defined by the following response:

Milk stage. A milky substance is secreted, indicating an immature seed lacking viability.

Soft-dough stage. Seed has a doughy texture, indicating it will have low germination and viability if collected.

Hard-dough stage. No excretion of dough or milky substance when squeezed. Seeds are collected at this stage. Seeds can be collected at the transition between soft-dough and hard-dough stages. If collection occurs between these stages, seeds should not be stripped from the plant. Instead, seed heads should be cut and placed in collection bags where seeds will continue to mature.

Mature. Seeds in this stage are usually too hard to bite. Collection should begin immediately because seeds can dislodge from the stem at any time.

to identify individual collection areas for approval prior to collection. Since seed collection can start in late spring for some species, collection site location must be completed by this time.

Collection areas for each species should not occur in one location, but represent a cross-section of populations in the general area of the project. A minimum of five collection areas, at least a mile apart, should be identified for each species. This ensures that a range of genetic characteristics is represented in each seedlot. While some populations will be located in the project area, most areas will have to be found in adjacent areas. When seed collection is conducted outside of the project area or agency administered lands, permission must be obtained from the landowner or manager.

Collection sites must be free of any plants listed as noxious weeds by the Oregon Department of Agriculture ("A and B" weed lists) because of the potential of seed contamination. Once located, the collection sites should be marked with flagging at a point easily visible from the road used to access the site. The flagging should have a written description that includes the GPS location (including elevation and UTM [Universal Transverse Mercator] coordinates) or a compass bearing and approximate distance in feet from the access road to the collection site. Each site should be approved by the revegetation specialist/botanist. Locations will be numbered sequentially and the location placed on 7.5° topographic maps and each collection site must be described and documented in the field notes.

10.2.1.6 Collect Seeds

Only viable seeds that are visually sound and sufficiently mature should be collected. Seeds are considered sound when the embryo is developing normally and there is no evidence of insect, disease, climatic, or other types of damage. Seed maturity in plants with fleshy fruits (many shrub and some tree species) often corresponds with changes in color (e.g., color changes from green to red, blue, purple, or white), taste (higher in sugars when mature), or hardness (fruit softens with maturity). Wind-dispersed seeds (which include many of the conifer species) usually change from green to brown when ripe. For grass species, seed maturity can be determined by how seeds respond to being squeezed (Inset 10.11). Since seed ripeness is influenced by the local weather and microclimate, determining seed ripeness often requires several monitoring trips to the field prior to collection.

Seed collection techniques are tailored to the species being collected. Grass and forb species, for instance, can be hand-harvested by stripping or clipping stems just below the seed heads and placing them in collection bags or containers. Collection bags should be made of materials that allow airflow, such as paper or fine mesh. Plastic bags or plastic containers should not be used. Other methods of collecting grass and forb seeds include mechanical flails and vacuums. While these methods can increase seed harvesting rates significantly, they must be done on nearly pure stands of a single species to avoid contaminating the seedlot with more than one species. Some forbs, such as lupine (*Lupinus* spp.), have indeterminate inflorescence, which means they continuously bloom, starting from the bottom of the flower head and progressing to the top (Figure 10.52). These species present a problem in seed collection because seeds

***Figure 10.52** – Species such as lupine (*Lupinus spp)*.have indeterminate inflorescence bloom and set seeds all summer. Seeds ripen first at the bottom of the stem and continue to ripen up the stalk as the season progresses.*

ripen continuously through the growing season. Seeds from these species are often obtained by making multiple trips to the field and collecting seeds from the lower portions of the stem without disturbing the flowers or immature seeds above.

Seeds of many shrub species are often collected by holding a bag or tray under the plant and shaking the plant or flailing the branches with a stick or tennis racket. While the seeds of some shrub species ripen and remain on the seed head, others, such as *Ceanothus* spp., shatter when they ripen and must be collected as soon as they ripen. Since multiple collection trips can be expensive, an alternative approach is to enclose the seed head of each plant in a mesh or paper bag before the seeds have begun to ripen. At the end of the season, ripened seeds will have dispersed into the bags, which can be easily collected. The seed collection contractor should specify the methods that will be used for collection.

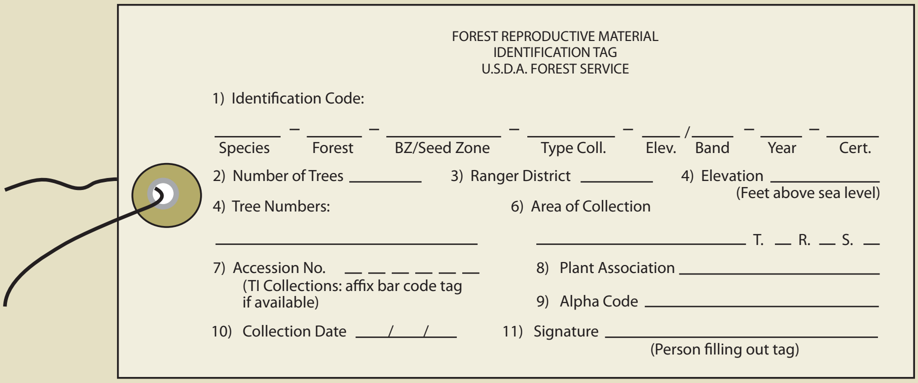
Seeds should be collected in approximately equal quantities from approved collection areas (See Section 10.2.1.5). To ensure adequate genetic representation, collect from a large number of widely spaced or unrelated parent plants per area (over 50 is optimal). To preserve populations, no more than 50% of the seed crop at each site should be collected in a year. Seeds or seed bearing fruits should not be collected from the ground.

Each seed collection bag or container must be clearly identified in the field with the following information:

- Species (scientific name),
- Forest or BLM district,
- District or BLM resource area,
- Legal description,
- Date of collection,
- Name of collector,
- Number of populations collected,
- Elevation, and
- Road project name.

The Forest Reproductive Material Identification Tag is an excellent way to capture this information (Figure 10.53). These are often available at Forest Service district offices or seed extractories. To assure the identity of the seedlot in case the tag is accidentally removed during handling or shipping, it is a good idea to duplicate the tag and place it into the collection bag. Field collections must be grouped into seedlots prior to sending these collections to the seed extractory for cleaning. Individual collections within a species are only maintained as separate seedlots if the objective is genetic testing or research. The expense of cleaning, packaging, and keeping records of a multitude of collections outweighs the necessity of storing them separately.

***Figure 10.53** – A Forest Reproductive Materials Identification Tag should be completed and attached to each collection bag sent to the seed extractory. A copy should also be placed inside the bag.*


FOREST REPRODUCTIVE MATERIAL
IDENTIFICATION TAG
U.S.D.A. FOREST SERVICE

1) Identification Code:

____ – ____ – ____ – ____ – ____ / ____ – ____ – ____
Species Forest BZ/Seed Zone Type Coll. Elev. Band Year Cert.

2) Number of Trees ______ 3) Ranger District ______ 4) Elevation ______
(Feet above sea level)

4) Tree Numbers: ______ 6) Area of Collection ______ T. __ R. __ S. __

7) Accession No. _ _ _ _ _ _ _
(TI Collections: affix bar code tag if available)

8) Plant Association ______

9) Alpha Code ______

10) Collection Date ___ / ___ / ___

11) Signature ______
(Person filling out tag)

The information displayed on the seed tag can be used to identify or name a seedlot. Each seedlot is identified by a seedlot identification code constructed in the following manner:

Species - Forest - Seed Zone - Elevation - Project Name - Collection Year

Species **–** The species short code can be obtained from the Plants Database on the National Resource Conservation Service website (http://plants.usda.gov/index.html).

Forest or BLM District Office **–** This is a numerical number assigned to each forest or BLM district office.

Seed Zone or Breeding Zone **–** For conifer and many native species, seed zones and breeding zones are geographic areas that have been identified by geneticists. Consult with the local reforestation, botanist, or area geneticist for seed zone and breeding zone maps.

Elevation **–** Elevation is generally listed as a range and abbreviated for conifer and many native species (For example, a 4,000 to 5,000 elevation band is listed as 4,050).

Project Name **–** The highway or revegetation project name is usually abbreviated.

Collection Year **–** The year in which the seeds were collected is abbreviated.

Certification **–** Certification codes apply to conifer tree species and are used to differentiate what is known about the parentage of the seeds. For example, codes pertain to whether the seeds were collected from the wild, seed collection areas, seed orchards, or if seeds are from tested material.

For example, the seedlot code, ARNE-10-502-2030-Elk-04, identifies a pinemat manzanita (*Arctostaphylos nevadensis*) seed source, collected on the Rogue River National Forest in seed zone 502 in an elevation range of 2,000 to 3,000 ft. Seeds were collected for the Elk Creek Road project in 2004.

Inset 10.12 – State Certified Seed Testing Laboratories

Oregon State University Seed Laboratory
Corvallis, OR 97331-3801
Telephone: 541.737.4464

Washington State Department of Agriculture
21 North 1st Avenue, Suite 203
Yakima, WA 98902
Telephone: 509.225.2630

Idaho State Department of Agriculture
3340 Kellogg Lane
Boise, ID 83712
Telephone: 208.332.8630

Inset 10.13 – Seed Tests
(modified from Tanaka 1984)

Seed testing is used to evaluate seedlot quality and provide information for determining sowing rates for seed and seedling production. Methods used for seed testing are based on rules of the Association of Official Seed Analysts (AOSA). A number of tests are normally conducted on each seedlot to evaluate physical and biological seed characteristics.

Physical Characteristics

Purity. Purity tests are used to determine the percentage by weight of four components: 1) pure seeds of the desired species, 2) seeds of other species, 3) weed seeds, 4) inert matter, such as stems, chaff, scales, and small stones. Graminoid seeds with more than 10% to 15% inert matter will be difficult to apply through a rotary seeder or rangeland drill. Purity tests should verify the seedlot contains no "prohibited" noxious weed seeds and meets or exceeds standards for "restricted" or "other weed seeds" according to state standards for Certified Seed. Because each state has different lists of prohibited and restricted noxious weeds, it is important to request an "All-States Noxious Weed Exam." While not prohibited or restricted by the State, some aggressive non-natives found through seed testing may still pose a threat to native plant communities.

Moisture content. Seed moisture content for most species is determined by oven-drying. Seed samples are weighed and heated at 105 °C (221 °F) for 16 hours, then weighed again. Seed moisture is expressed as the percentage of the weight of the water lost over oven-dry weight. Electronic moisture meters are also frequently used, but are not as accurate as the oven-drying method. They give rapid measurements when checking moisture in a large number of seedlots.

Moisture tests are important for determining the storability of seeds. Typically, seed moistures for long-term storage should be less than 10%.

Seeds per pound. Seeds per pound is the weight of a given number of seeds of the desired species, and does not include seeds of other species or weed seeds. The method weighs 100 seeds of ten random samples and converts the values to number of seeds per pound.

Biological Characteristics

Germination. A germination test conducted in a controlled environment is the most reliable method for testing seeds. At least 400 seeds from the pure-seed component of the purity test are used in the test. Depending on the species, the seeds are usually divided into four replicates of 100 seeds each and chilled (stratified) for a pre-determined period and placed on trays in controlled germination chambers. At 7-day intervals, the number of seeds that have germinated (when all essential structures appear normal) are counted (AOSA 2002).

Tetrazolium staining. Although controlled-environment germination tests are reliable, they are also time-consuming, particularly for those species requiring chilling. A rapid method of estimating viability is tetrazolium (TZ) staining. This test is preferred if results are needed immediately, or if species to be tested have unknown chilling or germination requirements, which is often typical of many native species (Rauch 2006). The TZ test requires seeds to be immersed in 2,3,5-triphenyl tetrazolium chloride. Living cells stain red as the chemical is reduced by dehydrogenase enzymes to form a stable red triphenyl formazan, which is insoluble in water. Seeds are cut and the embryos are that are red-stained are counted as viable seeds. This test is very useful for native species that produce seeds that are dormant and will not germinate without after-ripening (that is, seeds placed in an environment where they will continue to ripen) or without special germination enhancement treatments (stratification, scarification, gibberellic acid, and so on). In these cases, germination tests usually report out lower viability rates than actually exist. Since TZ tests measure the percentage of live embryos, they typically give a better indication of potential germination rates.

X-ray. At least 400 seeds, divided into four replicates of 100, are x-rayed and evaluated for presence of mature embryos, insect damage, filled seeds, damaged seeds, and other seed characteristics that might affect germination. X-raying is a quick test, but not as accurate as germination or TZ tests.

10.2.1.7 Clean and Test Seeds

Wild seed collections must be cleaned to a standard that can be uniformly applied through seed sowing equipment for seedling production or seed increase. Seed extractories have the experience and equipment to clean wild seeds of most species. Seed cleaning is typically completed in two to three steps: 1) removing seeds from cones or seedpods (conifer species and some hardwood tree and shrub species), 2) detaching structures from seeds, and 3) removing all non-seed materials from collections. Removing seeds from most conifer cones involves using tumbling equipment to allow seeds to separate from scales. Some conifer species and many shrub and hardwood species require specialized equipment to break open the seedpod without damaging the seeds. Detaching seed structures involves the mechanical removal of awns (grasses), wings (conifers), and fleshy structures (shrubs). Once seed structures are detached, all non-seed materials, including stems and chaff, can be removed from the collections, leaving only pure seeds. Seed extractories will dry, package, and store seeds, as well as test seeds on-site or send seeds to a testing facility. It must be noted that seed extractories cannot improve a poorly collected seedlot. For example, seed extractories cannot remove weed seeds, damaged seeds, or immature seeds from a collection, nor separate seeds from different crop species mixed in a seedlot. Prior to collecting wild seeds, it is important to contact the seed extractory manager to discuss which species will be cleaned. Seed extractory managers are great sources of information on collection and care of a variety of native species seeds.

Cleaned seeds should be tested for germination, purity, seeds per pound, and presence of noxious weeds (Inset 10.13) by an approved seed testing laboratory (Inset 10.12). Testing requires representative samples be collected from each seedlot. Seeds are usually stored in large sealed drums or bags. Seeds should be sampled with probes that reach to all parts of the storage container. If there are multiple containers per seedlot, samples from each container should be drawn in proportion to the size of the container. Since the amount of seeds needed for testing may vary by species and laboratory, seed testing facilities should be contacted prior to submitting samples for special instructions.

Seed viability usually decreases with time in storage. Seed testing should be conducted every few years, or at least the year before it is sown, to obtain the most accurate germination rates. Copies of seed tests should be retained in contract files and on seed inventories.

10.2.2 COLLECTING WILD CUTTINGS

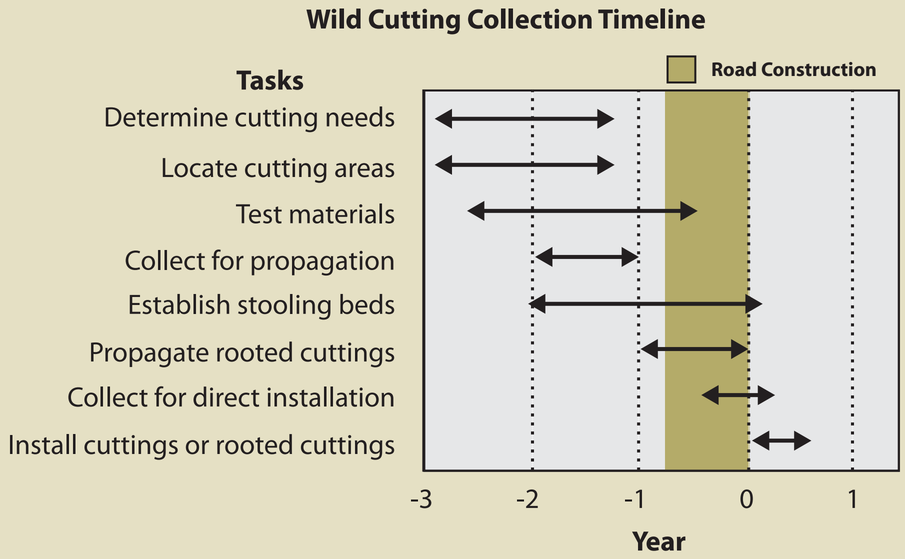
10.2.2.1 Introduction

Using cuttings can be a viable alternative to planting seedlings or sowing seeds to reestablish native vegetation. Vegetative material is collected from stems, roots, or other parts of donor plants and directly planted on the project site or sent to a nursery to produce rooted cuttings. The potential to produce roots from vegetative cuttings varies by species – from easy to propagate to extremely difficult. The most common species propagated from vegetative cuttings are shrubs and some trees. Many deciduous species that grow well in riparian settings, such as willows (*Salix* spp).and cottonwoods (*Populus* spp.), have a high success rate when propagated from cuttings. Most temperate evergreen trees and shrubs, however, only root under very controlled environments with specialized propagation techniques.

The intent of this section is to provide the reader with a greater understanding of how to select and collect cuttings in the wild. The primary focus will be on the species in the genera *Salix* and *Populus*, because these are these are most frequently used for direct sticking. Most other temperate tree and shrub species must be sent to the nursery for the production of rooted cuttings before they are installed on project sites (In tropical and subtropical areas, a wider variety of species can be collected as wild cuttings).If temperate species other than willow and cottonwood are considered for propagation, nurseries should be contacted to determine the best methods for selecting, cutting, and handling the material.

Cuttings can be obtained from wild collections or from cultivated stands of donor plants, called stooling beds. Stooling beds are established at nurseries or other agricultural facilities from wild collections. In this section, we will focus on how to obtain cuttings from wild locations and leave the discussion of producing cuttings from stooling beds to Section 10.2.5, Nursery Cutting Production.

***Figure 10.54 –** Collecting wild cuttings requires a lead-time of several years depending on whether it is used to propagate stooling beds, rooted cuttings, or direction installation.*



Wild cuttings are used in revegetation projects when 1) seeds or seedlings are difficult to obtain, 2) seeds germinate poorly in the nursery, or 3) cuttings are needed for biotechnical engineering objectives. Seed yields can be low for many species due to a variety of reasons, including poor pollination, disease, and insect damage. Some species, such as pinemat manzanita (*Arctostaphylos nevadensis*) and Pacific yew (*Taxus brevifolia*), produce seeds which can be very difficult to germinate in nursery environments. Other species, which include many tree species, produce seeds on an irregular basis; there may be many years between seed crops. Some seeds are difficult to collect either because they are inaccessible (in the upper portions of trees) or the window of seed collection is very narrow (e.g., *Ceanothus* spp.). For these species, starting plants in the nursery from rooted cuttings may be the only viable and economical alternative (See Section 10.2.6, Nursery Plant Production). Another important use of cuttings is in biotechnical engineering projects. These projects combine the physical strength of cuttings with root strength of establishing plants to increase surface and slope stability (See Section 10.3.3, Installing Cuttings).

When considering the use of cuttings over seeds or seedlings, the benefits must outweigh the potential limitations. Some factors that can limit the successful establishment of cutting material are the accessibility and availability of donor plants, how well the material roots (rooting potential), and how well the material survives once it has rooted. A common oversight when working with cuttings is forgetting that this material is alive and subsequently handling the material poorly. Another oversight is collecting cuttings outside of dormancy, when plants are actively growing. Neglecting either of these facts often leads to failed revegetation projects. This implementation guide covers the major factors that are important to consider when working with wild cuttings.

10.2.2.2 Develop Timeline

Locating cutting areas in the field might seem like a simple task, but it can be quite difficult when you are faced with such realities as land ownership, accessibility of the cutting areas to roads, winter weather conditions, and poor quality of plant materials. For these reasons, a lead-time of several years should be considered for projects requiring large quantities of wild cuttings (Figure 10.54). On large projects, sufficient lead-time allows for the location of potential collection sites and testing of the rooting potential of cutting material. If cuttings are used to propagate stooling beds (See Section 10.2.5), which are recommended for large projects, cuttings need to be collected at least 2 years or more before cuttings are installed on a project site. If the material is to be used to produce rooted cuttings at a nursery, the material should be collected at least a year prior to installation. When the materials are cut for direct installation on a project site, the cuttings will be made in the fall through winter prior to planting.

10.2.2.3 Locate Cutting Areas

The vegetation assessment during the planning phase (See Chapter 6) is an opportunity to locate potential sources of cuttings. During this field survey, cutting sites are mapped and assessed for the following characteristics:

Proximity and Accessibility – Good sources for cuttings are not always found within the project site, so it is necessary to survey large areas. Sometimes good collection sites are miles away from the project, which can substantially increase costs. However, the benefits of collecting quality plant materials far outweigh the additional transportation costs. The large size and weight of cutting materials often limits collections to areas adjacent to and accessible by roads. Poor road conditions during the winter months, when cuttings are most likely to be collected, should be considered in site selection, because of the potential of being closed by snow or winter road damage. It is often possible to collect quality cutting material within the right-of-way clearance, which is identified during the vegetation assessment.

Ownership – Some of the best collection sites may be on private lands. Always obtain permission from the landowner prior to collecting. Cutting from areas located on federal, state, and local government managed lands must be coordinated through these agencies. Observe collection standards for size and quantity dictated by the landowners.

Viability – The quality of the cutting material is an important criteria for determining the suitability of a collection site. Determining the viability of the collection material should be completed prior to selecting the collection site (See Section 10.2.2.4).

Genetic Considerations – It is important to determine if the species to be collected is monoecious (male and female reproductive parts on the same plant) or dioecious (male and female reproductive parts on different plants). If the species is dioecious (Inset 10.14), such as willow or cottonwood, an attempt to collect cuttings from both male and female plants in equal amounts should be made. If one of the objectives for using dioecious species is to promote or restore a species, donor plants must be located during periods of identifiable phenology, which is typically spring through summer. This might add an additional year to the timeline. To help preserve genetic integrity, it is recommended to collect from a minimum of 50 donor individuals within a watershed (See Chapter 6 for genetic transfer guidelines). Differentiating between individual plants within an area can be difficult with clonal species, such as willows and cottonwoods, because what often appear as a group of individual plants are actually offshoots from a single parent plant.

Diameter Size – The project objectives will determine which stem diameters must be collected (NRCS 1997). This must be assessed when a collection site is evaluated.

Small diameter. Small diameter materials, called branched cuttings, average less than 1.0 inch in diameter and are derived from the fine branches of vigorously growing donor plants. This material is tied into long bundles to form live fascines (See Section 10.3.3.4, Live Fascines) or laid on the surface of the soil to form brush mattresses. Live fascines are placed in shallow trenches on slope contours to function like small water and sediment collection dams, or they are placed at an angle to the slope to facilitate slope drainage (See Section 10.3.3.3, Live Brush Layers). Small diameter materials are also used for branch packing and to vegetate geogrids and rock gabions. Additionally, small diameter materials are used for rooted cutting production at nurseries. The typical diameter size preferred by most nurseries ranges from 3/8 to 1/2 inch.

Medium diameter. Medium diameter cutting materials are used to make live stakes (See Section 10.3.3.2, Live Stakes), which range in size from 1.0 to 3.0 inches in diameter. Stakes are tamped into the ground at right angles to the soil surface to secure small slumps, live fascines, and erosion control materials. Joint plantings are stakes that are driven between rocks or riprap, and must be greater than 1.5 inches in diameter and several feet long. Materials ranging from 0.5 to 2.5 inches are used to revegetate live crib walls. Crib wall cuttings must be long enough to reach 4 to 6 feet back to the end of the wall.

Large diameter. Larger diameter materials are used as dormant post plantings to stabilize streambanks. The diameter of these poles range from 3 to 5 inches and are 7 to 9 feet long. Large posts are not always easy to obtain in the wild, but can be produced from nursery stooling beds.

Inset 10.14 – How to Tell the Difference Between Male and Female Willows and Cottonwoods

Identifying the sex of dioecious plants is easiest when they are flowering or fruiting. Willow (*Salix spp)*.catkins may appear before, during, or after new leaves appear in spring. Identifying anthers in male catkins (photo A) and pistils in female catkins (photo B) with a hand lens is relatively easy, especially with a little practice. Female plants can easily be identified when the cottony seeds are mature (photo C). During the winter dormant season, it is possible to identify the sex of dormant cottonwoods by dissecting floral buds, although this is more difficult with willows. Detailed instructions on how to sex willows and cottonwoods can be found in Landis and others (2003).

Cutting Footage **–** The total length of cuttings available for harvest should be estimated for each potential cutting area. This can be roughly calculated by evaluating 10 to 20 donor plants and estimating the average length and number of usable stems (by diameter size categories) that could be obtained from each. The average length is then multiplied by the estimated number of plants in the cutting area to obtain a total estimated cutting footage. This will be the high end of an estimate, since most landowners are likely to place a restriction on the amount of cuttings that can be harvested at one time. For example, a landowner might limit the amount of cuttings that can be taken from an area to 25% in a riparian area. The cutting footage would be 25% of the total length of the cuttings.

10.2.2.4 Determine Rooting Potential

Not all cuttings will root and become established plants when installed on a project site. The success rate of those that actually do become plants is dependent on 1) the percentage of cuttings that form roots when placed in an ideal growing environment, or the rooting potential and 2) the percentage of viable cuttings (those that root) that become established after a growing season, or the survival potential.

Rooting potential is analogous to germination rates obtained from seed testing. Seed tests are performed under uniform, ideal growing conditions, and are a measure of the potential of seeds to germinate (See Sections 10.2.1, 10.2.4, and 10.3.1). Rooting potential is similar to germination in that it assesses the potential of cutting materials to produce roots under an ideal rooting environment. The potential of cutting materials to initiate roots is the basis for determining how many cuttings to collect and the density to plant. For example, if the rooting potential of a specific collection is low, more cuttings will need to be planted at closer spacing to compensate for those cuttings that do not root.

Root potential tests have been developed for measuring the viability of nursery-produced plants (Ritchie 1985), but there are no standardized tests for determining the rooting potential of cuttings. Labs that offer seedling quality tests might, on request, use or adapt the root growth potential (RGP) tests developed for seedlings to assess the rooting potential of vegetative materials. Inset 10.15 gives one possible method for assessing rooting potential.

Rooting potential is affected by several plant factors, the most important of which are 1) species, 2) genotype, 3) date of collection, 4) portion of plant collected, 5) age of material, 6) condition of material, 7) preparation techniques.

Species – A small percentage of species in the western United States root consistently from cuttings. Those that root well can be cut and used directly on revegetation projects. Other species initiate roots only under controlled nursery environments, and must be grown into rooted cuttings before they can be planted on a project site. A list of commonly used native species that root from cuttings are shown in Table 10.13.

Genotypes – Within each species, there is variability in rooting potential. Some donor plants (genotypes) will have greater rooting potential than other plants. Unless tests are run, it is hard to know which donor plants are optimal rooters.

Date of Collection – The optimal time to collect cutting material is during plant dormancy. For most willow and cottonwood species, this period extends from mid-fall, after the donor plant drops its leaves, to bud swell in late winter to early spring. It is safe to assume that if donor plants have lost their leaves, cuttings will be at their highest rooting potential.

Planting unrooted cuttings within the dormancy period is not always possible because most construction work is curtailed during winter months. If unrooted cuttings must be planted outside the dormancy period, establishment rates will significantly decrease. There are several alternative measures that can be taken: 1) collect cuttings during dormancy and keep in cold storage until they can be installed (See Section 10.2.2.7), 2) collect cuttings outside the dormancy period and plant more cuttings to compensate for the anticipated downfall (See Section 10.2.2.5), or 3) use rooted cuttings in lieu of unrooted cuttings (See Section 10.2.2.4).

***Table 10.13** – Some common species that can be propagated from vegetative material.*

		Rooting Potential	
Species	**Vegetative Material**	**In Field**	**In Greenhouse**
Willows (*Salix* spp.)	Stems	Easy	Easy
Cottonwoods (*Populus* spp.)	Stems	Easy	Easy
Snowberry (*Symphoricarpos albus*)	Stems	Easy to Moderate[1]	Easy to Moderate[1]
Pacific ninebark (*Physocarpus capitatus*)	Stems	Easy to Moderate[1]	Easy to Moderate[1]
Black twinberry (*Lonicera involucrata*)	Stems	Easy to Moderate[1]	Easy to Moderate[1]
Douglas spirea (*Spiraea douglasii*)	Stems	Moderate[1]	Moderate[1]
Salmonberry (*Rubus spectabilis*)	Stems	Moderate[1]	Moderate[1]
Quaking aspen (*Populus tremuloides*)	Roots	Poor	Moderate
Redosier dogwood (*Cornus sericea*)	Stems	Moderate[2]	Moderate
Chokecherry (*Prunus virginiana*)	Roots	Moderate[2]	Moderate
Golden currant (*Ribes aureum*)	Stems	Poor	Moderate[2]
Woods' rose (*Rosa woodsii*)	Stems	Poor	Moderate[2]
Manzanita (*Arctostaphylos* spp.)	Stems	Poor	Moderate

[1] From Darris and Williams 2001
[2] From Bentrup and Hoag 1998

Inset 10.15 – Testing Method for Determining Rooting Potential for Willow and Cottonwood Species

Testing the viability of willow and cottonwood cuttings takes much of the guesswork out of establishing plants through this method of propagation. While is not a common practice in revegetation work, testing the viability of cuttings should be considered for similar reasons as seed testing. Most revegetation specialists would not think of applying seeds on a project without first testing for germination, purity, and seeds per pound, yet not think twice about using cuttings without having tested them first. This oversight can lead to higher costs, as well as low establishment rates.

There are no established testing procedures for assessing rooting potential of cutting materials. Until these tests are established, we present a means of root assessment that can be used to compare results from year to year. Ideally, a controlled environment, such as a greenhouse, is the best place to conduct a rooting potential test. Temperatures should range between 65 and 75 ° F degrees. Using bottom heat or rooting hormones is not necessary; in fact, for some species, it can be detrimental for rooting (Darris and Williams 2001). Where a greenhouse is not available, use an indoor space where relatively constant temperatures can be maintained. Grow lights should provide at least 12 hours of light per day.

Fifteen samples, at a minimum, should be randomly collected from different donor plants at each collection area. They should be of the same size and treated in a manner similar to what would be expected under normal operations. For example, if stakes with diameters between 2 and 3 inches are to be collected in August and soaked for 10 days before planting, then the cuttings used for the tests would be of similar size, collected in August, and soaked in the same manner, and planted. Prepare each sample by cutting them into 12-inch lengths. Stick them 3 inches apart in pots that are at least 16 inches deep, filled with 1 part peat to 4 parts perlite. Cuttings should be stuck so that two buds are exposed above the media.

After sticking, water the pots and set them in their testing location. At weekly intervals, observe the cuttings and note the status of the leaves developing from the buds. At 28 days, record how many cuttings have developed new leaves, gently remove the media from around the cuttings, and lightly wash the stems. Viable cuttings should have developed roots during this period. Record how many cuttings did not initiate roots (see cutting on the left in picture below). For those cuttings that did establish roots, a quantitative estimate of root initiation can be measured by removing the roots from the stem and weighing the new roots or counting the number of new roots for each cutting.

To interpret this data, you will have to assume that any cutting that did not initiate roots or develop foliage during 28 days, probably will not immediately initiate roots in the field. A comparison of average root weights or number of roots between testing samples can indicate which collection sites or treatment methods will produce the best rooting materials. Those test samples with high average root weights should perform better than those with lower weights.

Collecting plant materials outside the dormancy period has been tried in biotechnical engineering projects with varying degrees of success (Figure 10.55). Species that root easily, such as willows (*Salix* spp). and cottonwoods (*Populus* spp.), will root from cuttings collected outside dormancy, albeit at very low rates (Steinfeld 2002; Steinfeld 2005). In some instances however, this may be the only option available to the revegetation specialist. When these are the circumstances, collecting outside the dormancy period should be done with an understanding of how establishment rates will be affected and whether the overall project objectives will be met. For large projects, it is important to conduct rooting and survival potential tests (Inset 10.15) several years before cuttings are installed so that the appropriate amount of cuttings can be collected and planting densities can be determined (See Section 10.2.2.5). An alternative to dealing with low survival potential of wild cuttings is to establish stooling beds (See Section 10.2.5).

***Figure 10.55** – Collecting cuttings outside of plant dormancy as was done for the project shown in this photograph, can lead to extremely poor results. If this practice is considered, rooting potential tests should be performed first.*

Portion of Plant – Most cuttings are taken from stems and branches. However, the rooting potential for some species is greatest when cuttings are taken from roots (Table 10.13).

Age of Material – The rooting potential changes with the age of the donor plant. Many species have greater rooting potential from new growth, while others perform better when materials are collected from older branches or stems. Species having a higher rooting potential in the older portions of the plant make excellent live stakes because the size of the material is often large enough to withstand being driven into the ground (Darris and Williams 2001).

Condition of Material – Vegetative material from donor plants can be affected by insects and disease which can severely reduce rooting potential (See Section 10.2.5 for more discussion).

Preparation Techniques – Several practices can potentially enhance rooting potential. One method involves soaking dormant cuttings in water prior to planting. Schaff and others (2002) found that soaking black willow (*Salix nigra*) for up to 10 days in water doubled the survival rates of large diameter, dormant cuttings over unsoaked cuttings. Some revegetation specialists have reported an increase in rooting potential of cuttings collected outside the dormancy period by stripping leaves from stems, while others have found this ineffective (Steinfeld 2002). Soaking cuttings in hormones can increase rooting in some species (Shaw 2004), while it can be detrimental to others (Darris and Williams 2001). Testing rooting treatments on a small scale through rooting potential tests should be conducted prior to applying these methods on a larger scale.

10.2.2.5 Determine Survival Potential

Not all cuttings that initiate roots under ideal testing conditions will establish into plants when outplanted on a project site. The percentage of viable cuttings that root and survive one year after planting is called the survival potential. The survival potential is controlled by 1) climate, 2) soils, 3) planting methods, and 4) maintenance practices for each project. It can be determined though field testing conducted prior to installing cuttings, or estimated from previous field experience on similar sites using unrooted cuttings, rooted cuttings, or planted seedlings.

***Climate* –** Survival potential is strongly influenced by the water loss potential of the site (See Section 5.4). Sites with low moisture stress during root initiation (typically spring through early summer) will have high survival potentials. The longer cuttings can initiate and grow roots without being under moisture stress, the greater the potential for survival. Climates with high humidity during root initiation occur in riparian areas.

Within a project area, survival potential often changes with aspect. Cuttings subjected to hot, dry conditions of south aspects typically will have a lower survival potential than north aspects. Survival potential also increases in areas that have occasional summer rainstorms that wet the soil profile.

***Soils* –** Survival potential is affected by soil water storage and accessibility (See Section 5.3). Soils with low water-holding capacity will have lower survival potentials than those with high water-holding capacity. Installation of cuttings on compacted soils will result in lower survival than loose or tilled soils. Areas that have high water tables during the growing season, such as slumps, seeps, and springs, will have higher survival potentials for riparian species.

***Installation Methods* –** Compensations can be made for sites with poor soils or dry climates. One option is to install longer cuttings. Studies have shown that higher survival rates and greater vegetative growth can be achieved with longer cuttings (Rossi 1999). This is especially important on drier sites, since longer cuttings access deeper soil moisture. Cuttings up to 2 feet in length have been shown to produce better survival and growth on harsher sites (McElroy and Dawson 1986; Rossi 1999). In areas where freeze-thaw potential is high (See Section 5.6.2), shorter cuttings have a greater likelihood of being pushed out of the ground before they can form roots to anchor them in place. Survival rates are also affected by the quality of planting methods. For instance there can be a significant decrease in survival when cuttings are planted without good soil–to-stem contact and many large air pockets. Section 10.3.3 covers the different methods of installing cuttings.

***Plant Maintenance* –** Survival potential can also be increased if the plants are maintained during the first year after planting, including the control of competing vegetation and protection from animal browse (See Section 10.4, Post Installation Care of Plant Materials).

10.2.2.6 Determine Cutting Needs

Once the survival and rooting potentials have been determined, the quantity of cuttings to collect can be calculated. The information needed for determining cutting quantities and cutting spacing (density) is:

- Rooting potential,
- Survival potential,
- Target plant density,
- Area to plant,
- Desired established plant densities, and
- Length of cuttings.

An example of how to calculate cutting quantities and planting spacing is shown in Figure 10.56. In this example, the project objective is to stabilize the slope by installing willow stakes. In the short term, this practice will increase slope stability by physically "pinning" the surface soil. The primary benefit to slope stability, however, will develop over time as the roots of the establishing willows begin to tie the soil particles together and increase soil strength. The desired spacing between established plants is 6 ft. When inventories are taken one year after planting, they should find an established plant approximately every 6 feet (D), or approximately 303 established plants for the entire planting site (E).

To achieve the desired density of established plants, we must determine how many cuttings to plant and the average spacing between installed cuttings. This determination is based primarily on the rooting and survival potentials (See Section 10.2.2.4 and Section 10.2.2.5). In this example, the rooting potential was 68% based on rooting potential tests. The survival factor was estimated to be around 35% from previous experiences on similar sites. These factors are used in the equation shown in Line F, to calculate the number of cuttings needed to install. To obtain 303 established plants, it would be necessary to install approximately 1,271 cuttings. This is approximately four times the number of established plants. It is necessary to install this

Figure 10.56 – This spreadsheet can be used to calculate the number of cuttings to collect and how close to plant them on the project site.

A	Area to plant:	0.25	acres	Area that will be planted with cuttings
B	Rooting potential:	68	%	Percent of cuttings that root under ideal rooting environment
C	Survival potential:	35	%	Percent of cuttings that root which are established one year after planting
D	Target plant spacing (1st year):	6.0	feet	Desired distance between established plants after one year
E	(43,560 / (D * D)) * A =	303	plants	Desired number of established plants after one growing season
F	E * (100/B) * (100/C) =	1,271	cuttings	Number of cuttings that need to be planted
G	Cutting Length:	2.5	feet	Approximate length of cuttings
H	F * G =	3,178	feet	Total footage of cuttings to collect for site
I	SQRT ((43,560 * A) / F) =	2.9	feet	Distance that cuttings must be planted from each other

many to compensate for the number of cuttings that either do not root, or root and do not survive the summer. The planting spacing is calculated using the equation in Line I. Cuttings must be installed at half the distance of the desired established plant spacing. Since the site conditions in this example are harsh, the cuttings will need to be planted deeply to access soil moisture. For this reason, the cutting lengths are approximately 2.5 ft. Multiplying 2.5 ft by the number of cuttings needed (F) gives the total length of cuttings that must be collected (H). Knowing that 3,178 ft of cuttings are needed, the number and location of cutting areas can be selected from a cutting area map, and a contract can be developed.

10.2.2.7 Long-Term Storage

If cuttings are not installed immediately, long-term storage will be required. Cuttings collected in the fall or winter and stored until the following spring or summer must be held in refrigerated units. The optimum temperatures for long-term storage range between 28 to 31 °F. Freezing temperatures prevent disease and curtail respiration, thereby increasing cutting viability. If freezing is not possible, then storing cuttings at temperatures between 33 and 35 °F should maintain cutting viability for several months.

For long-term storage, cuttings should be relatively free of leaves and other material that might mold in storage. They must be packaged in plastic or storage bags so they will not dry out. Cuttings should not be wrapped in moist burlap or placed in plastic bags, especially if cuttings are not frozen. Diseases could potentially develop that will rot the stems.

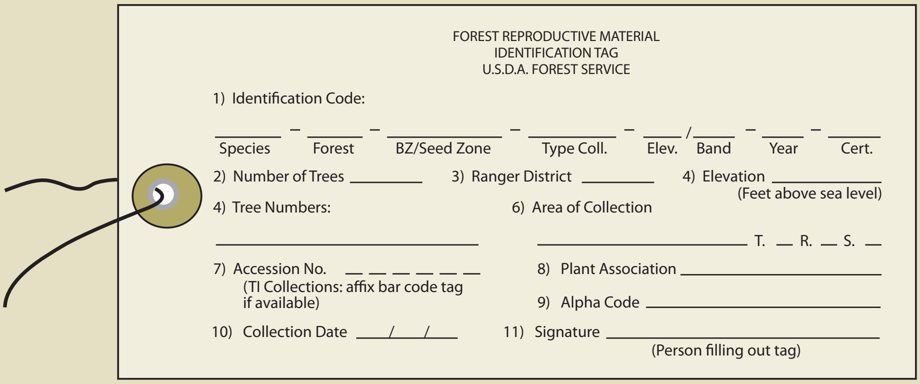
10.2.2.8 Develop and Administer Contracts

A good plan that includes the location of cutting sites and how the cuttings will be treated, transported, and stored will be the basis for the development of a collection contract. The contract must specify:

Cutting Locations – A map or GPS locations must identify cutting areas and specify an estimated range of cutting quantities (See Section 10.2.2.3). If the contractor elects to collect from other areas, then these areas must be approved prior to cutting. For each cutting area, the percentage of the donor population that can be collected should be specified. Typically this is no greater than 25% of the population.

Dates of Collection – The contract must specify a period of time that cuttings must be collected (See Section 10.2.2.4). Collecting outside this time period must be discussed in advance with the revegetation specialist.

Figure 10.57 – A forest reproductive material identification tag should be filled out and attached to each bundle of cutting material.


FOREST REPRODUCTIVE MATERIAL
IDENTIFICATION TAG
U.S.D.A. FOREST SERVICE

1) Identification Code:

____ – ____ – ____ – ____ – ____ /____ – ____ – ____
Species Forest BZ/Seed Zone Type Coll. Elev. Band Year Cert.

2) Number of Trees ____ 3) Ranger District ____ 4) Elevation ____ (Feet above sea level)

4) Tree Numbers: ____ 6) Area of Collection ____ T. __ R. __ S. __

7) Accession No. __ __ __ __ __ __ (TI Collections: affix bar code tag if available) 8) Plant Association ____

9) Alpha Code ____

10) Collection Date __/__/__ 11) Signature ____ (Person filling out tag)

Collection Size, Lengths, and Quantities **–** Quantities must be specified for each size category. For example, if material is to be used for stakes, then a specification might require 200 stakes, 18 inches long, with a range of diameters between 1.0 inch to 3.0 inches.

Collection Methods **–** The contract should identify how the contractor will collect the cuttings. For example, it should state how the contractor will identify which end of a stake is basal and which is terminal. This is typically done by cutting the basal end of each stake at an angle. The contract should also specify how the cuttings will be packaged or bundled. Contracts often call for all stakes to be aligned with basal ends of the cuttings in the same direction. Bundle sizes or weights must be specified. The bundles must be light enough to transport by one person (45 lb or less). The contract must also state that the bundles must be securely tied or bundled together for hand transportation.

Source Identification **–** Each bundle must be identified with a Forest Reproductive Materials Identification Tag (Figure 10.57), which specifies the species, collection location, elevation, and date of collection.

Special Treatments – Special measures such as soaking must be stated in the contract. If soaking is required, then the location of the soaking area must be identified on a map (See Section 10.2.2.4).

Temporary Storage and Transportation **–** The contractor must address how cuttings will be temporarily stored when the weather is warm or dry. Cuttings must not be allowed to dry out once they are collected. Temporarily storing in shaded areas covered by plastic sheets or wet burlap are acceptable methods. Delivery of cuttings must be done in a manner that does not allow the cuttings to dry. Closed transportation or covering with plastic for long distances should be considered.

10.2.3 COLLECTING WILD PLANTS

10.2.3.1 Introduction

Wild seedlings, commonly referred to as wildlings, are indigenous plants growing in their native habitat (Therrell and others 2006). They are naturally reproduced outside of a nursery situation, but can be transplanted directly into a restoration site or into a nursery for culturing and future use.

The collection and use of wildlings in native plant restoration can be a viable alternative to direct seeding, nursery seedlings, or rooted cuttings. As with wild cutting collections (See Section 10.2.2), wildlings can be used in situations where it is difficult or impossible to collect or use seeds for plant production because : 1) the plant either does not produce seeds or produces seeds very infrequently; 2) seeds are often unfilled or non-viable; 3) seeds have a very narrow collection window; 4) seeds have already dispersed prior to collection planning; and 5) insects or animals are a problem with collection (Priadjati and others 2001; St John and others 2003). Unlike cuttings, they can be available immediately with little to no transport costs, and no direct nursery costs, if used within the same time frame of collection.

Figure 10.58 *– Wetland plants are often salvaged from areas that are planned for disturbance. Removing plants from wetland settings can be difficult due to wet soils and massive root systems of many species. The heavy weight of these plants makes transportation and handling difficult. Tubs (A) are used for hand-transporting to planting sites while pallets (B) have been used for large quantities.*

There are several advantages to using wildlings in restoration plantings. Large wildlings provide "vertical relief" (visual prominence) more quickly to a site than other methods, and, depending on the species and environment, will establish and spread quickly (Hoag 2003). Use of wildlings reduces the risk of introducing non-native organisms such as weeds and pathogens (Therrell and others 2006). If reproduction of the plant is more successful via rhizomes (e.g., sedges), transplanting wildlings may be the most efficient and effective method for reestablishing these species (Steed and DeWald 2003). In addition, if plant propagation is difficult from seeds or rooted cuttings, use of whole plants may be the only alternative for a particular species.

Transplanting of wildling plants, however, can be unsuccessful for a number of reasons. Wildlings are often growing in stressful conditions, and do not recover from transplanting shock as quickly as cultivated seedlings. Wildlings often have smaller, coarser root systems than cultivated seedlings, or heavier taproots which are not easily removed from soil in their entirety (St John and others 2003). Successful transplanting requires experience, skill, proper handling, ideal temporary storage, and proper care of the plant both before and after transplanting.

10.2.3.2 Develop Timeline

Although wildling plants may provide an opportunity for quick establishment of larger plants on restoration sites, several factors must be considered in the planning process which could impact their availability. Suitable locations that can provide the number of plants required must be determined. If large quantities of plants are necessary, several years may be required to identify these locations. Once sites are identified, 1 or 2 seasons of plant preparation prior to removal, transport, and transplanting may be required (See Section 10.2.3.5).

Wildling plants may be removed from their native site and either transplanted immediately or transported to a nursery, potted, and cultured for future outplanting. Transplanting following removal may occur if the plant source is undisturbed areas outside the restoration site. If plants are removed prior to site disturbance, or if additional time is needed for production of sturdy plants, culturing in a nursery for some specified period of time may be necessary. Lead time of 1 to 2 years may be necessary for nursery-assisted wildlings, depending on the situation. This lead time may include contract procurement and administration for both collection and nursery culturing.

10.2.3.3 Locate Wildling Collection Areas

Potential sources for wildling plants can be identified through field surveys during the vegetative assessment phase (See Chapter 6). Sites should be located on maps and both plants and sites should be assessed for the following traits:

Accessibility **–** Handling of wildling plants during removal and transport is a critical factor in ensuring survival. Roots may require protection if the rootball is not totally contained in soil; or plants may be heavy if the rootball is intact. Therefore, it is necessary that collection sites be accessible by roads. Since most collections will be taken in fall or early spring, it is also necessary to determine whether or not road conditions at these times of year will preclude collection.

The best collection areas may not always be found within the project site, so large areas surrounding the project may need to be surveyed for plants. Costs will increase substantially if it is necessary to transport plants for long distances.

Land Ownership **–** Permission to remove plants must always be obtained from either the private landowner or public land management agency. In addition, any required permits should be obtained from state or federal agencies to ensure compliance with regulations (Hoag 2003).

Viability **–** If possible, areas of healthy forest or rangeland areas should be designated as collection sites (Priadjati and others 2001). Sites should contain healthy, vigorous, and adequately sized material with a minimum number of unhealthy plants (St John and others 2003). Stunted needles, off-color foliage, and poor annual growth are indications of stress plants that should not be collected. Plants should only be removed from sites that show good regeneration over the area (Hoag 2003). Determining the viability of the collection material and timing of use (See Section 10.2.3.4) should be completed prior to selection of the collection site. It is important to transplant wildlings into similar growing environments. For instance plants growing under shade should be placed back into a shaded environment to achieve optimum viability.

Genetics **–** One of the disadvantages or limitations of using wildlings, or any form of asexual propagation, in restoration is the potential to restrict the genetic diversity of the plant population. As adequate population sampling is important to maintain this diversity, it may be advisable to identify several sites over a large area from which to collect (St John 2003). Collecting many plants over a large area will help capture both inherited and environmental variation. However, sites must be chosen carefully so that they are reasonably similar.

Prior to collection, it is necessary to determine whether species are monoecious (male and female reproductive structures on the same plant) or dioecious (male and female reproductive structures on different plants). If the species of interest is dioecious, both male and female plants will need to be collected in somewhat equal proportions. If one of the objectives for using dioecious species is to promote, restore, or increase species, then target plants must be located during a period when reproductive phenology is evident, which is typically spring through summer.

10.2.3.4 Determine Transplanting Versus Nursery Culture

Although cost may be the biggest deciding factor in whether wildlings are collected for immediate transplant or growing in a nursery, other factors should enter into the decision in the restoration plan.

Timing **–** Wildling plants should be transplanted into their new location as quickly as possible. If plants are to be collected from sites outside the disturbed area, these can potentially be removed and transplanted to the restoration site within the same time frame. However, if plant removal is part of a salvage operation, where plants are located within the area of disturbance, then plants could be transported to a nursery or similar growing situation. Plants should be transplanted into pots and maintained until the appropriate outplanting season.

Species **–** Some plant species may be more successful than others for direct transplanting from one site to another. Plants that spread underground or with stolons will perform well, although dry, compacted sites will slow the rate of spread significantly (Therrell 2006). Species that recover quickly from root damage, such as willows (*Salix* spp).and cottonwoods (*Populus* spp.), will also perform well when large plants are needed quickly. These types of plants may lend themselves easily to transplanting within the same time frame as removal.

Plants with taproots, such as conifers and many shrubs, and plants with long, brittle horizontal roots, such as heather or vine maple, are difficult to transplant. Special care must be taken during removal to extract as much of the roots as possible. To ensure a higher success rate, further culturing in an optimal environment following removal may provide a healthier, more viable plant for outplanting.

Size and Availability – If wildling plants of the target species are plentiful and appropriately sized on undisturbed sites, immediate transplant during the appropriate season is feasible. However, if available wildlings are smaller than desired, an additional 1 or 2 years of nursery culture may provide a better plant for colonization of the site.

Certain plants have the ability to root by layering, such as pinemat manzanita (*Arctostaphylos nevadensis*). If entire plants are not plentiful, portions of individual plants can be removed and cultured in a nursery situation for outplanting the following year.

10.2.3.5 Collection and Handling

Date of Collection and Timing of Transplanting – The season during which collection and transplanting occur has been shown to dramatically affect the survival and growth of wildling plants (Yetka and Galatowitsch 1999). Plants allocate carbohydrates and nutrients during various phases of phenological development. Different levels of tolerance to transplanting stress during the year are the result of physiological needs shifting among shoot and root growth, flowering and seed production, and storage. In addition, seasonal variation in environmental factors, such as soil moisture and temperature, can affect planting establishment (Steed and DeWald 2003).

Timing of collection will depend on whether the wildlings are to be transplanted in the same time frame or cultured in a nursery. If wildlings are to be transplanted into the restoration site following collection, the chances for survival will increase for most species if operations occur in winter to early spring. The seedlings are dormant during this period and can handle the stresses associated with transplanting. There is also less chance of damaging new roots that occur during the spring and fall. In addition, planting early extends the period for root growth prior to soil-drying in summer.

Collection could occur in either fall or spring if wildlings are to be cultured in a nursery. However, if plants are collected in the fall, care must be taken to avoid excessive root damage, since plants will not be dormant. Due to the perishable nature of wildlings, the timing of collection must be coordinated with the nursery to assure that the facilities, supplies, equipment, and labor are available following harvest (St John 2003). Once collected, plants should be transplanted immediately into containers.

Genetics – Collection of wildlings can consist of a single plant, a clump, or several pieces of a plant that have rooted through layering (NRCS 1997). A collection of individual plants should be large enough to assure adequate population sampling. A minimum of 50 plants within at least a range of 1 mile from the restoration site is recommended when possible.

Source Identification – Every collection must be identified with a Forest Reproductive Materials Identification Tag, which specifies the species, collection location, elevation, and date of collection (See Figure 10.53 in Section 10.2.1, or Figure 10.57 in Section 10.2.2).

Figure 10.59 – *Be sure to select small plants with a protective ball of soil around the roots (A). Do not attempt to transplant plants if the soil falls off the root system (B).*

Quality and Size – Only healthy, turgid, moderately vigorous, and adequately sized wildlings should be collected for either transplanting or nursery culturing. Unhealthy or stressed plants should be avoided.

Although species dependent, successful transplanting typically increases as plant size decreases (St John 2003). Transplanting of large shrubs and trees is usually unsuccessful. Their root-to-shoot ratio is unbalanced, and these plants often do not recover from or survive transplanting shock. Transplanting of larger willows, sedges, or herbaceous material into riparian zones, however, may be appropriate depending on the vegetative competition and other establishment conditions (Hoag 2003; Steed and DeWald 2003).

Handling, Transport, and Storage – Collection of wildling plants will be most successful if the soil is moist during plant removal. If precipitation has not occurred, irrigation prior to lifting would be desirable. Removal and transplanting should only occur in the mornings on cool, cloudy days, when the plant is fully turgid.

A tile spade or similar flat-bladed shovel is the best tool for small to medium plant removal. Using the "dripline" of the plant as a guide, make shovel cuts with the blade as perpendicular to the surface of the ground as possible, since maintaining an intact ball of soil around the roots is important (Figure 10.59). Root morphology should also be considered in this process. Roots growing in deep soils or arid soils will tend to grow down rather than out. Roots growing in shallow soils will tend to spread, requiring a much larger area of disturbance (Therrell 2006).

The shovel, as well as hands, can be used to lift the root ball gently out of the hole while attempting to keep the root ball intact. Hand pruners can be used to cut away woody roots that do not come free with the shovel. The root ball can then be transferred to a suitable container (large bucket, pot, burlap, or plastic bag) for transport to the transplanting site (Therrell 2006). If wildlings are to be transported to a nursery, plants should be placed in plastic bags in coolers. Plastic bags should also contain moistened towels or similar material if roots are not covered with soil.

A tree spade can be used if larger plants are to be excavated and transplanted (Figure 10.60). The factors important for using a tree spade are: 1) the terrain is accessible to the tree spade equipment (slope gradients no greater than 20%), 2) soils are relatively free of cobble size rock fragment, and 3) soils are moist. In this operation, planting holes are created first, then plants are excavated, moved, and replanted. The size of the plant to be transplanted depends on the soil volume that can be removed by the tree spade. Typically plants up to 6 feet tall can be transplanted with success. Taller trees should be irrigated into the soil to improve survival. Using a backhoe has also been successful in transplanting large willow clumps (Hoag 2003).

Wildlings should be transplanted into their new location as quickly as possible, with minimal to no storage time. All vegetative material must be kept cool and moist during the process. If wildlings are transported to a nursery, the plants should be kept in a cooler and transplanted into pots within 1 to 2 days of collection.

Figure 10.60 – *Plants can be excavated from the soil using the drip line (dashed lines) as a guide.*

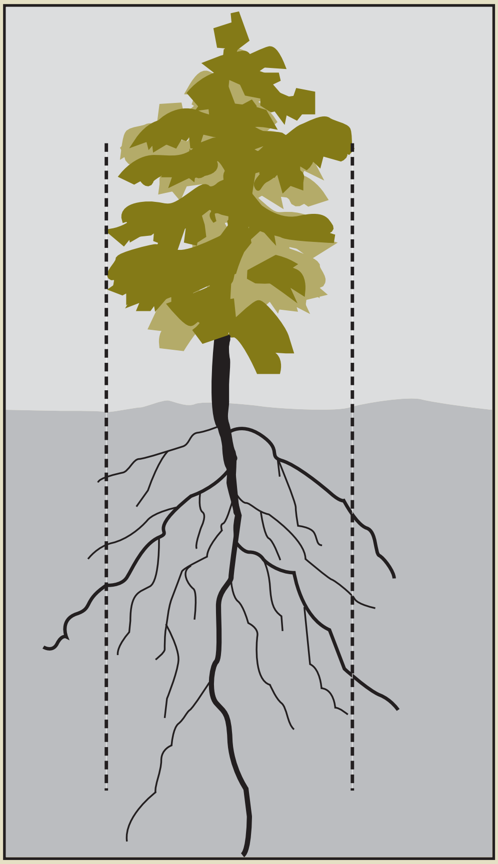


***Figure 10.61** – Mechanical tree spades (A) can extract large plants quickly. A planting hole must be excavated prior to transplanting (B) and this can be accomplished with a tree spade. Photo credit: Chris Jensen, USFS.*

10.2.3.6 Survival Potential

As with rooted cuttings (See Section 10.2.2.5), not all wildlings will become established and thrive following transplanting. Survival is controlled by climate, soils, planting methods, and maintenance practices on the project.

Climate – Water loss potential (See Section 5.4) is probably the main determining factor for survival on many sites in the western United States. Sites with low moisture stress during root initiation (spring through early summer), and sites that have the potential for longer root initiation periods, will have higher survival.

Within a project area, aspect can also affect root initiation and survival. Transplanted wildlings subjected to hot, dry conditions on southern aspects have a lower potential for survival than those on cooler northern aspects.

Soils – Survival of wildlings is affected by soil water storage and accessibility (See Section 5.3). Soils with low water-holding capacity or compacted soils will have lower survival than those with high water-holding capacity and greater porosity.

Planting Methods – Good transplanting techniques will improve the survival rates of wildlings significantly. Planting methods are the same for wildlings and nursery-grown seedlings. Common mistakes include planting too shallow or too deep, planting too loosely, damaging roots by exposing them to air, or failing to place root systems properly (Therrell 2006).

Ideally, transplanting should occur on a cool, cloudy day. Planting holes should not be allowed to stand empty for an extended period of time, as soil will dry rapidly. When possible, microsites should be used (rocks, logs, depressions, and so on) to provide protection from the sun or wind.

Plant Maintenance – Survival potential can also be increased if the plants are maintained during the first year after planting. Practices including the control of competing vegetation and protection from animal browse. For large wildlings, irrigation during the summer will improve survival. Also large wildlings might need additional support depending on such site conditions as wind and snow.

10.2.3.7 Develop and Administer Contracts

A plan that includes the location of collection sites, and how the wildlings will be handled, transported, transplanted, and stored (for short periods of time) will be the basis for the development of a collection contract. The contract must specify:

- ***Collection Locations.*** A map or GPS locations must identify wildling collection areas and specify a range of quantities that can be expected. If the contractor elects to collect from other areas, then these areas must be approved prior to collection. For each collection area, it should be specified what percentage of the natural population can be collected.

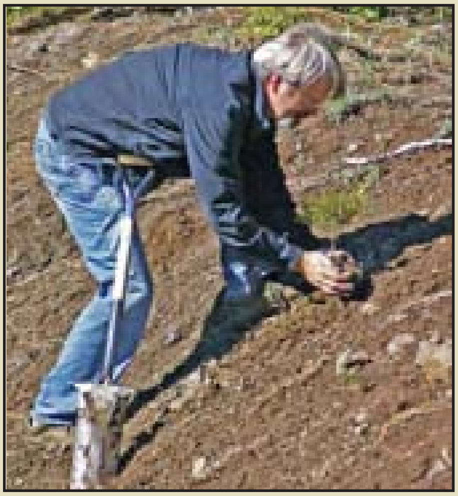


Figure 10.62 *– Transplant wildlings immediately following collection to minimize moisture stress.*

- ***Dates of Collection.*** The contract must specify a period of time that the collections can be made (See Section 10.2.3.5). Collecting outside of this time period must be discussed in advance with the revegetation specialist.
- ***Collection Quality and Size.*** Minimum and maximum plant sizes should be specified in the contract. In addition, specifications for health and vigor should be included.
- ***Collection, Handling, and Storage Methods.*** The contract should identify how the collections will be made, how the wildlings will be handled and processed following removal, and how wildlings will be temporarily stored prior to transplant or transport to the nursery.

The contractor must address how plants will be temporarily stored when the weather is warm or dry. Wildlings must not be allow to dry out once they are collected. See Section 10.2.3.5 for proper handling and storage methods.

10.2.4 NURSERY SEED PRODUCTION

10.2.4.1 Introduction

Most revegetation projects require large quantities of source-identified seed. The most common approach to obtaining such quantities is to issue seed increase contracts. In these contracts stands of grasses and forbs are established from source-identified seed (typically wild seed collections) and cultured specifically to produce seed (Figure 10.63). Usually the seeds are produced by the end of the first or second year of production.

Considering the costs and amounts of seeds that can be obtained from wild seed collection, propagating grass and forb seed is very efficient. For example, mountain brome (*Bromus carinatus*) requires 8 pounds of wild seed to sow an acre of seed fields. At the end of the first year, the seed collected from the field will average 800 pounds, a hundred-fold increase. For most species grown in production beds for two years, the return is at least 50 pounds of seed produced for every pound of wild seed collected and sown. In some cases 100 pounds are collected per pound of wild seed sown. This section will outline the steps required for developing and administering seed increase contracts.

10.2.4.2 Develop Timeline

Seed production varies by species but typically it takes three years to obtain seed. This involves one year to obtain seed from wild collections, and at least two years for seed production (Figure 10.64). There are a series of steps or tasks that are required to obtain seed that will be discussed in detail in this section:

- Determine seed needs,
- Obtain starter seed,
- Develop and award contract,

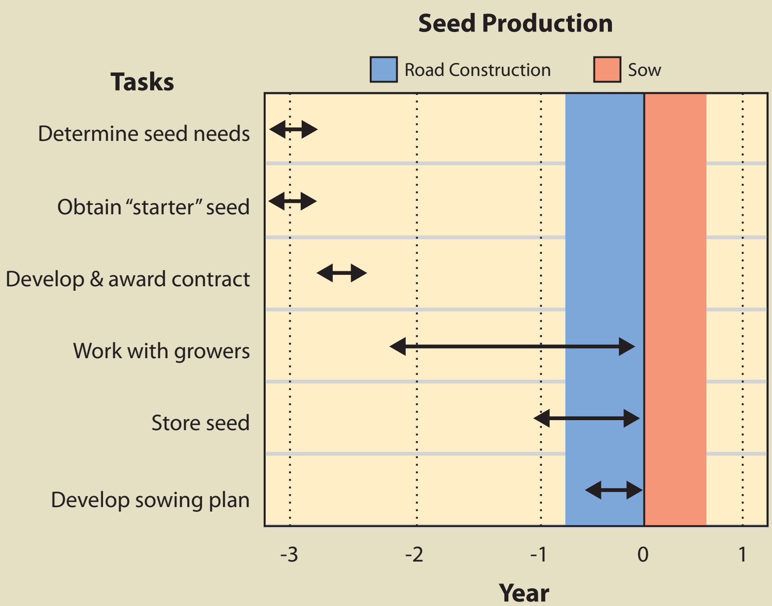
***Figure 10.63** – A variety of species can be propagated for seed. In this photograph small seedlots of forbs are being propagated. The beds in the upper left are western buttercup* (Ranunculus occidentalis); *lower left is fragrant popcornflower* (Plagiobothrys figuratus), *and the bed on the right is elegant calicoflower* (Downingia elegans).

- Administer contract, and
- Store seed.

Early in the planning phase a rough approximation of the quantity of needed seed for each species must be determined. Seed quantities will be refined as planning progresses, but because of the amount of time that is takes for wild seed collection and seed production, it is important to make an estimate early in the planning stages. Developing and awarding wild seed collection contracts is the first task and this can take several months (See Section 10.2.4). To avoid missing the seed collection window, these contracts must be awarded by early spring, otherwise an additional year will be needed for wild seed collection.

Seed production contracts should be awarded by mid-July for fall sowing and late January for spring sowing. It is important to prepare and award seed increase contracts well in advance of sowing to allow the contractor enough time to prepare and sow their fields. Specific sowing dates will differ for each seed producer because of differences in geographic location, climate, or experience. Some growers may want to certify the seed, so this may require additional

***Figure 10.64** – Up to three years should be allowed when obtaining nursery grown seed because of the time it takes to obtain wild collected seed and obtaining seed from seed producers.*



preparation time as well. It is beneficial to contact the potential growers prior to award of contracts to find out when sowing and first harvests are expected. Once wild seed has been collected, cleaned, and tested, it is delivered to the seed producers.

Seed increase contracts should cover a span of at least two years, to account for the possibility of a low first year harvest. Seed harvests take place during the summer and seed cleaning in the fall of each year. Once seed has been cleaned, the grower submits a sample from each seedlot to a seed laboratory for testing. Seed testing typically takes place in the fall and is completed in several months. Seed is placed into seed storage until it is needed. For many revegetation projects, the seed that is harvested in the summer is needed for immediate fall sowing. This can be accomplished if those seedlots are put on a "fast track" for seed cleaning and testing. The seed production contract should state those seedlots that need to be ready for early fall sowing.

10.2.4.3 Determine Seed Needs

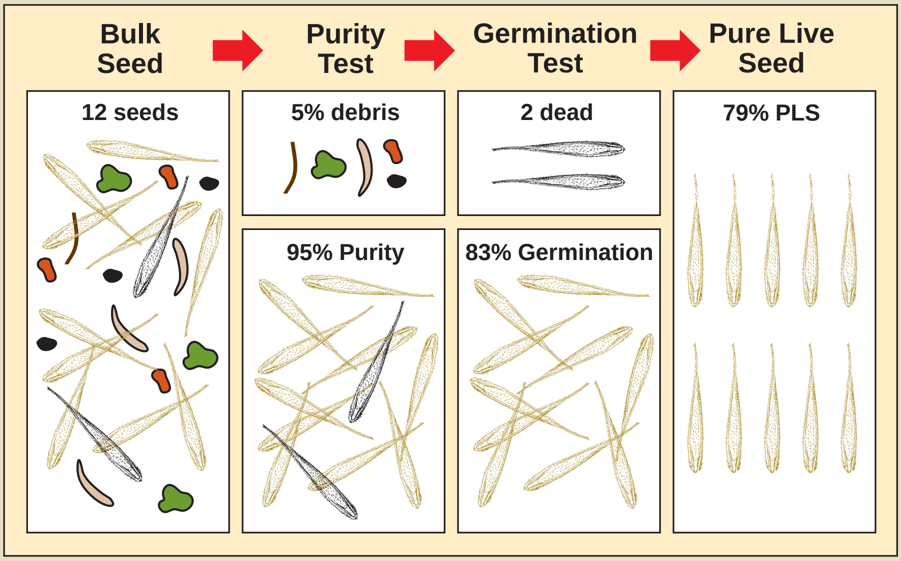
Determining total seed quantities for a revegetation project must be done as soon in the planning process as is feasible since wild seed collection contracts and seed propagation contracts are based on these figures. At this point, only a rough approximation of seed needs is required.

Calculating the needed quantities of seed is performed for every species that will be used on a revegetation project. Each species requires a set of data which must be estimated since specific seed data is unavailable at this point in planning. The information that is needed includes an estimate of the following factors:

- Pure live seeds per pound,
- Field survival,
- Target seedling density,
- Target species composition, and
- Area to seed.

***Pure Live Seeds Per Pound (PLS/lb)* –** The quality of seedlots can vary greatly. One method to assess seed quality is to calculate % pure live seed (PLS). This value represents the percent of the gross seed weight composed of viable seeds. For example, if a seed producer did not clean the harvested seed of a seedlot very thoroughly, the PLS would be low because there would be a lot of additional weight associated with non-seed debris. Seedlots that were cleaned well, on

***Figure 10.65* –** *Pure live seed (PLS) is the percent of the bulk seed weight that is composed of viable seed. In this example 95% of the bulk weight is composed of seed and of this seed 83% was found to germinate from seed tests. Multiplying % purity by % germination gives % pure live seed.*



the other hand, would have a higher PLS because the debris weight would have been removed. Seedlots that have higher germination rates also have higher PLS. These two factors, % purity and % germination, when multiplied together and divided by 100, give the pure live seed (PLS) of a seedlot. The concept of PLS is illustrated in Figure 10.65. In this example, purity of a grass seedlot is 95% and germination is 83% which results in a PLS of 79%.

Another example of calculating PLS/lb is shown in Figure 10.66 for western pearly everlasting (*Anaphalis margaritacea*). For this seedlot the estimated purity is 60% which indicates that over half of the gross weight of seed is actually viable seed and the remaining part is either debris or non-viable seed. Multiplying this value by the percent of seeds per pound and by the percent of germination will yield the number of viable seeds per pound. In this example, the number of seeds in a pound of a western pearly everlasting seedlot is tested at 8,000,000. Multiplied by 60% purity and 85% germination gives a value of approximately 4,080,000 PLS per pound of bulk seed. This value can be used in sowing calculations as shown in the example. Keep in mind that for each additional seedlot in a mix, similar calculations will have to be made. Estimates for purity, germination, and seeds per pound can be obtained from Table 10.14, seed inventories, or seed extractory managers.

Field Survival **–** Field survival factors account for the viable seeds that, for one reason or another, do not grow into plants within the year after seeding. It accounts for viable seeds that did not germinate because of the harsh site conditions, or did germinate but could not survive the site. The field survival factor reflects the harshness of the site. For example, seeds that are sown under mulch on a moist, cool site will survive better than seeds sown on hot, dry sites without mulch, in which case the survival factor would be much lower. Only an estimate of field survival can be made at this time, based on general understanding of the site (See Section 10.3.1.5 for more discussion on estimating survival). Choosing a survival factor between 3% (poor site conditions and poor seeding practices) and 25% (good site conditions and practices) should be sufficient for this estimate. In Figure 10.66, the field survival was set very low because of the harshness of the site.

Target Seedling Density **–** The target first year density indicates the number of plants/square foot that is desired one year after sowing. This is the target number of seedlings, for all species sown, in a one square foot area. Seedling densities range from a target of less than one plant per square foot for shrub and tree species to 10 and 25 seedlings per square foot for grasses and forbs (See Section 10.3.1.5).

Figure 10.66 **–** *Determining the quantity of seed that will be needed for a revegetation project can be made by completing this spreadsheet for each species. The estimated pounds of seed determined for each species can be the basis for ordering seed through a seed increase contract. This example calculates the quantity of western pearly everlasting (*Anaphalis margaritacea *[ANMA]) seeds needed for a project.*

A	Number of seeds/lb:	8,000,000	seeds/lb	From Table 10.14 or other sources
B	Purity:	60	%	From Table 10.14 or other sources
C	Germination:	85	%	From Table 10.14 or other sources
D	A ∗ B / 100 ∗ C /100 =	4,080,000	PLS/lb	Pure Live Seeds (PLS) per bulk pound of seed
E	Field survival:	3	%	Estimate of the pure live seeds that become seedlings (as low as 3% for harsh sites and up to 25% for excellent sites)
F	Target seedling density:	25	seedlings/ft^2	Desired number of seedlings per square foot — all species (10 to 30 for grasses and forbs)
G	Target composition	10	%	Percent of total plants composed of ANMA
H	(F / E) ∗ G =	83	PLS/ft^2	PLS of ANMA to sow per ft^2
I	43,560 ∗ H / D	0.9	lbs/acre	Pounds of ANMA to sow on a per acre basis
J	Area to seed:	25	acres	Total area for seed mix
K	I ∗ J =	22	lbs	Total ANMA needed

Table 10.14 – *A seed increase reference table showing the approximate maximum cleaned seed needed for a seed producer to produce a 1-acre production field. It also shows average first and second year yields and germination and purity standards for commonly produced species.*

Species	Sowing Rates (lbs of clean seed to sow per acre)	Average first year yields (lbs/ac)	Average second year yields (lbs/ac)	Average seeds per pound	Average germination/ purity of harvested seeds
Bluebunch Wheatgrass *(Pseudoroegneria spicata)*	8	200	300	140,000	75/95
Blue Wildrye *(Elymus glaucus)*	6	450	200	110,000	65/96
Bottlebrush Squirreltail *(Elymus elymoides)*	6	0	125	110,000	75/90
California Oatgrass *(Danthonia californica)*	8	25	250	125,000	75/90
Basin Wildrye *(Leymus cinereus)*	8	25	160	130,000	75/95
Idaho Fescue *(Festuca idahoensis)*	4	50	400	450,000	75/90
Indian Ricegrass *(Oryzopsis hymenoides)*	6	0	200	120,000	80/85
Lemmon's Needlegrass *(Achnatherum lemmonii)*	8	150	750	150,000	50/95
Mountain Brome *(Bromus carinatus)*	10	800	600	70,000	85/90
Needle and Thread *(Hesperostipa comata)*	6	0	150	100,000	50/95
Pinegrass *(Calamagrostis rubescens)*	2	0	130	2,500,000	75/75
Prairie Junegrass *(Koeleria macrantha)*	2	150	500	2,315,000	80/97
Sandberg Bluegrass *(Poa secunda)*	3	300	600	1,314,000	75/97
Slender Hairgrass *(Deschampsia elongata)*	3	600	350	2,000,000	80/95
Thurber's Needlegrass *(Achnatherum thurberianum)*	5	0	150	225,000	50/95
Tufted Hairgrass *(Deschampsia caespitosa)*	2	110	510	2,500,000	75/90
Western Needlegrass *(Achnatherum occidentale)*	5	100	190	275,000	50/95
Common Yarrow *(Achillea millefolium)*	2	165	165	3,000,000	85/98
Western Pearly Everlasting *(Anaphalis margaritacea)*	1	50	50	8,000,000	60/85

Target Species Composition **–** The target composition defines the percent of established plants that are made up of each sown species. For example, if three species are sown, the target composition of plants might be 50% species A, 35% species B and 15% species C. The target species composition is developed from reviewing field surveys of disturbed and undisturbed reference sites. In the example shown in Figure 10.66, only 10 percent of the composition of plants is targeted to be pearly everlasting.

Area to Seed **–** This is the total area that is planned to be revegetated from seed based on the estimated acres presented in the preliminary road plans.

In the example shown in Figure 10.66, the seed needs for pearly everlasting is calculated to be approximately 22 pounds for the entire 25 acre project. This might seem like a very low amount of seed for a project of this size, but it reflects the high live seeds per pound for this species.

10.2.4.4 Obtain Starter Seed

Once the seed needs for a project are determined then the next step is to obtain starter seed to supply to the seed producer. Seed furnished to the seed producer must be of high quality and tested for purity, germination (or TZ), seeds per pound, and noxious weed content (See Section 10.2.1.7 for seed testing). Seedlots with high weed content will produce weedy fields. It is very expensive to weed non-target species out of seed production fields or clean non-target seeds from harvested seedlots, so it is important to give seed producers only the highest quality seed. It is worth the investment of sending all wild seed collections to a seed extractory to be cleaned prior to sending to the seed producer. Section 10.2.1.3 discusses how to determine how much wild seed to collect for starting seed production crops.

There will be some projects where not enough wild seed is collected to establish a seed crop through seed sowing. In these cases, small collections of seed can still be used by first sowing seed in small plugs (1 to 2 cubic inch size) at a nursery, then transplanting the plugs into a seed production field at low densities (<1 seedling per foot). Not only will this reduce the amount of seed needed to establish a seedbed but seed production from these beds is often greater because plants are evenly spaced.

10.2.4.5 Develop Contract

The seed production contract must state for each seedlot being grown:

- Seedlot ID,
- Years each seedlot will be in production,
- Minimum annual seed yields for each seedlot, and
- Minimum purity and germination rates.

Minimum annual seed yields and average germination and purity rates can be obtained from Table 10.14. The years that a seedlot will be in production will vary by species and lead-time (See Section 10.2.1.2 for further discussion).

In addition, the seed production contract must address what is required or expected of the contractor in respect to the following criteria:

- Seed production experience;
- Timelines;
- History of production fields;
- Location of other seed crops;
- Irrigation system;
- Culturing practices;
- Control measures for non-target species;
- Seed harvest methods;
- Seed cleaning, packaging, and labeling; and
- Seed testing.

The response to these criteria becomes the basis for selection of contractors.

Seed Production Experience – Seed production is a specialized form of agriculture requiring different growing strategies and equipment. While many seed producers have

Inset 10.16 – Source Identified Straw Bales

A secondary product from the seed production contracts is the straw that remains after harvest. This material can be used for erosion control or seed covering. It can be used as a mulch and has the additional advantage of being a source of unharvested viable seed. This product must be treated similarly to certified straw sources (See Section 10.1.3). There should be no noxious or undesirable weed seed in the bales. A visit to the seed production fields prior to seed harvest will indicate if there are any unwanted species that will be present in the hay bales. Bales of each seedlot must be kept separate from other sources to prevent mixing. If straw bales are stored for any length of time, they must be protected from rain.

transitioned in seed production easily, it still requires several years of experience to understand how to efficiently grow native seed. Many seed producers who have moved into growing native seed have previous experience growing vegetable or commercial grass seed. These seed producers bring great experience and perspective to the native seed industry. Seed producers who have had little experience growing seed, often start small with "easier" species (i.e., workhorse species) to gain experience. It is important to know the capability of each seed producer, and make frequent site visits. Those with a long history of good seed production can be contracted for species that are more difficult or have not been grown before. It is good to request production records, as well as seed tests, to include species, seed yields, seed quality, and clients served by the producer.

Seed Production Timelines – Seed producers are located in many parts of the western United States, covering a range of climates affecting when seeds are sown and harvested. It is important to know the general growing schedule of each seed producer to determine when you will need to supply starter seed to the seed producer and when the first shipment of harvested seed can be expected. Seed producers from east of the Cascade Mountains might need starter seed in the middle of the summer for an August sow, while those west of the Cascades might not need it until early fall. Some seed producers wait until the spring to sow seed crops, in which case the seed harvest in the first year may be significantly reduced. Depending on the climate, seed harvests occur as early as May to as late as August. It is important to specify a date in the contract when seed will be delivered, especially if you plan on using the seed in the same year it is harvested.

History of Production Fields – Every field will have some amount of residue seeds from previous crops which will germinate along with the starter seed. Knowing the history of the fields during the planning stages helps determine whether these non-crop plants pose a problem for the seed production. Noxious weeds or undesirable non-native species are obviously a real concern, but many of these species can be roughed out of the seed beds prior to harvesting. Of more concern are fields where the same native species, but from a different seed source, were grown. For example, a field is being prepared for sowing California fescue (*Festuca californica*) from a seed source in the Blue Mountains of northeastern Oregon. The field had previously grown California fescue from a seedlot collected west of the Cascades. Since seed from the previous fescue crop would germinate in the same bed, the resulting crop would include both seedlots. Since the plants from these seedlots would appear almost identical, it would be impossible to weed out the plants that came from the previous crop. Even species in the same genera are difficult to distinguish by untrained weeders and cannot be weeded out of beds.

Fields that previously produced seed from the same or similar appearing species should be evaluated for the risk of seed contamination from previous seed crops. There are measures seed producers can take to reduce contamination risks. These include growing non-seed crops for several years between seed crops, rotating between grass and forb seed production (forb seed is easy to discern from grass seed), and fumigating between seed crops. These strategies must be discussed with the seed producers.

Location of Other Seedlots – Equally important to the history of seed production fields, is the location of adjacent seed crops of the same species. If seedlots of the same species are being grown close by, the risk of cross-pollination between crops increases and the genetic integrity of the proposed seed crop would potentially be compromised. There can even be cross-pollination between similar species. For example, blue wildrye (*Elymus glaucus*), bottlebrush squirreltail (*Elymus elymoides*), and bluebunch wheatgrass (*Pseudoroegneria spicata*) are known to cross-pollinate. Talk to a local botanist or geneticist about which species can potentially cross breed. Seed crops that can cross-pollinate should also be separated by a minimum isolation distance. Under most circumstances, the isolation distances should be in accordance with State Certification Standards (certified class). These standards can be found at the departments of agriculture for each state.

Irrigation System – Many native species must be grown under irrigation to meet the quantities of seed specified in the contract. Seed producers that have minimal or no irrigation capacity are often unlikely to meet seed production requirements and time frames. Only those species that do not require irrigation should be offered to growers lacking irrigation systems.

Culturing Practices – A review of the culturing practices, which include irrigation, fertilization, disease, and insect control, should be done to determine whether they are appropriate for the

__Figure 10.67 –__ Seed harvesting equipment varies by seed producers and species being harvested. Discuss with the seed producer how each species will be harvested and see that equipment is cleaned between seedlots.

production of the species being grown. Culturing practices are often written up in propagation protocols that can be found at http://www.nativeplantnetwork.org.

Control Measures for Non-Target Species – Specific attention must be given to how weeds and other non-crop species will be controlled. Typical measures include 1) the use of herbicides prior to sowing and after the crop has been established, and 2) hand weeding of non-target species. The most important period of weed control is just prior to seed harvest because of the importance of eliminating potential non-target seed before seed harvest.

Seed Harvest Methods – Most seed harvests are carried out with specialized equipment that detaches seed from the stock, separates it from plant and soil debris, and collects it into storage containers (Figure 10.67). It is important to know the seed harvesting equipment that will be used for each species and how it will be cleaned between seedlot crops to prevent the possibility of seed contamination.

Species with indeterminate inflorescences (seeds that ripen on the seed stock all summer long) must be hand collected more than once in the summer. Periodic seed harvests of these species must be planned so that the full range of seed can be collected. The seed producer should address how these species will be harvested to obtain the maximum seed yield.

Seed Cleaning, Packaging, and Labeling – After seed is harvested, it must be dried and further cleaned. Seeds are air dried (Figure 10.68) or placed in a forced air drying system. Seeds are then extracted and cleaned. Awns and flower parts are removed and dirt, stems, and other debris are separated from the bulk seed. Understanding the cleaning operation is important because viable seeds can be damaged or discarded during this process.

Dry cleaned seed should be packaged in "breathable" woven poly bags at uniform weights. Industry standards are 25 or 50 lb bags. Bags of seed must be clearly identified (labeled by stencil or permanent marking pens, with characters at least 1 inch in size) with the Government's source seedlot identification. In addition, all bags should have an affixed tag stating the species name (scientific and common), seedlot identification, % germination, % purity (including other crop seed, weed seed, and noxious weeds), date of seed test, and seed producer's name. Additional labeling information may be requested, such as project name, National Forest or BLM office, or seed owner name.

Seed Testing and Acceptance – The contract must state the minimum acceptable standards for each species and seedlot. Acceptance and payment should be based on meeting the standards set for:

- Germination,
- Purity,
- Weeds, and
- Moisture content.

Seed testing is typically the responsibility of the contractor. Seed samples used for testing and contract performance must be taken by a certification agency representative or the contract inspector. Samples must be tested by a state certified seed laboratory (See Section 10.2.1.7). Seed test results must be identified by the seed source identification and task order number.

Figure 10.68 – Seed is harvested and dried prior to cleaning and storage. This photograph shows a recently harvested seedlot in drying trays prior to being set on a forced air drier. Seed ID tags are attached to the side of each seed drying bin.

Test results must be satisfactory to the Government before final acceptance of the seed is made.

Establishing minimum germination and purity rates can be based on averages obtained from commonly produced species shown in Table 10.14 or through discussion with seed extractory managers. The contract should address what actions the contractor can take to increase either germination or purity, if these rates fall below the standards. Lower purity rates can be accepted if seed will be used in a hydroseeder (See Section 10.3.2). A tetrazolium test (TZ) may be made in lieu of a germination test for a seed viability test depending on time constraints and species involved. All-State Noxious Weed examinations are required and if any of these species are present, then the seedlot is either rejected or recleaned. Seed moisture test must also be conducted and seed must not exceed 10% moisture.

10.2.4.6 Administer Contract

Seed producers are required to maintain adequate records to allow the Government to monitor contract progress. Records should include information and dates of field preparation, seed sowing, field treatments, fertilization, seed harvest, cleaning, storage, seed yields, and any other activity relating to seed production. It is a good practice to make contact either by phone or by visiting the seed producers two to three times a year to go over the progress of the contract. The best time of year for field visits is just prior to or during seed harvest. A visit or phone contact in fall is important to discuss the potential of keeping seedlots additional years. Unless it is stated in the contract, seedlots are likely to be plowed under once the seed orders have been met. Visiting in the late summer or fall is also a good time to observe the seed extraction and cleaning processes.

During these visits, it is important to note the condition of the seedlots and how they are being identified throughout the process; are there clear labels stating the seedlot identification in the

Figure 10.69 – It is important to visit seed producers to assess isolation distances, noxious weeds, culturing practices (e.g., irrigation, fertilization), and expected seed yields. The best period to visit is during seed ripening and seed harvest.

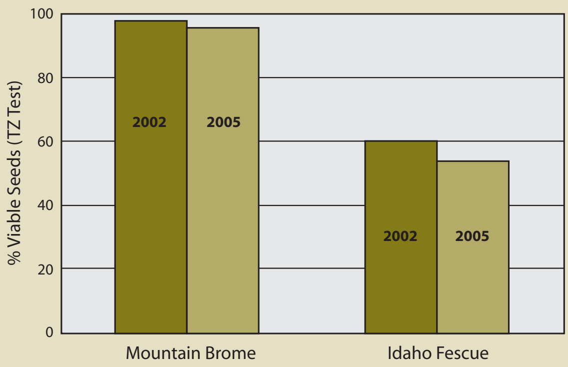


Figure 10.70 *– Properly cleaned, packaged, and dried seed can remain viable for many years under acceptable granary storage conditions. Seed germination for two Umatilla National Forest seedlots did not significantly decrease in storage after three years as shown in this graph (Riley 2006).*

field, during drying, extraction, and storage? Are seed harvest and extraction equipment being thoroughly cleaned between seedlots or are there remnant seeds remaining in the equipment that can contaminate the next seedlot being processed? Note the condition of the fields prior to seed harvest; are the fields weedy and will there be a final weeding before harvest? Are seeds being handled with care or are they roughly handled?

A good working relationship with the seed producer is essential in meeting the overall seed increase objectives. It should be realized that some factors, such as weather, are beyond the control of seed producers, and on some years seed harvests will fall short of the minimum amounts stated in the contract. Good communications with the seed producer will alert you to crop failures or fall down in orders as soon as they occur so that alternative measures can be taken. An inventory of the number of acres in each seedlot and the condition of the crop should be supplied by the contractor upon request.

10.2.4.7 Store Seed

Seeds can remain viable in storage for many years after harvest. How well seeds keep depends on the moisture content of the seed, the quality of the seed being stored, and the storage conditions (temperature and humidity). Riley (2006) found that there was minimal reduction of seed viability in granary storage after three years for mountain brome (*Bromus marginatus*) and Idaho fescue (*Festuca idahoensis*) (Figure 10.70). Seeds typically store poorly when seed quality is low or seed moisture content is above 10 percent. If seedlots are stored for more than a couple of years, it is important to periodically test the seed for germination.

Granary Storage – Most seedlots are stored for short periods of time before they are used on projects (usually less than five years). For this reason, granary storage is the most common and economical form of seed storage. Granary storage unit are enclosed rooms sheltered from rainfall and temperature extremes. They are typically insulated and protected from rodent and insects. Many granary storage units are tree coolers that have been reconfigured for this use. While seedlots can store for long periods, low quality seed should be used first because it is more likely that this seed will loose viability in storage, than high quality seed.

Freezer Storage – Freezer storage is usually reserved for seedlots that will be stored for many years. Conifer and shrub seeds as well as forb and grass wild seed collections are usually stored under these conditions, whereas bulk grass and forb seeds typically are not.

10.2.5 NURSERY CUTTING PRODUCTION

10.2.5.1 Introduction

Obtaining cutting materials in the wild for restoration and bioengineering applications can be a difficult and expensive task, especially if populations of parent material are small or access is limited. Native plant nurseries can be an alternative source of a variety of woody cuttings. Understanding how nurseries establish and manage "stooling beds" can be a great help to revegetation specialists and project engineers.

10.2.5.2 What are Stooling Beds?

"Mother plants" are established in nurseries for the sole purpose of providing a ready source of cuttings. Stooling beds are hedge-like rows of mother plants that are established in bareroot nurseries or in vacant fields adjacent to container nurseries (Figure 10.71A).

Stooling beds take advantage of the ability of many broadleaved woody plants to sprout profusely from the base after being cut off just above the root crown. Plants remain in the juvenile state, which means they have a higher tendency to sprout and produce roots. Once stooling beds are established, annual cutting ensures that juvenility can be prolonged indefinitely.

Stooling beds allow the efficient collection of dormant hardwood cuttings during the winter when it may be difficult or impossible to make field collections (Figure 10.71B). Because they are located at nurseries, the beds can be irrigated and cultured; processing and storing the cuttings is also much more efficient and cost-effective. Stooling beds have several advantages over wild collected cuttings.

Maintaining Genetic and Sexual Diversity **–** It is much easier to correctly identify different plant species and ecotypes from labeled stooling beds as compared to wild collections. For example, willows often grow together along streams and can be difficult to identify during the winter dormant season. Stooling beds offer the ability to produce a large number of cuttings of unique species or ecotypes quickly and easily.

Many government nurseries have established stooling beds of the species and ecotypes that are adapted to their local area and can thus be a potential source of cutting material for private growers or revegetation specialists. Private native plant nurseries are also establishing stooling beds of desirable species for their local areas, and several are specializing in riparian and wetland species. For specific revegetation projects, however, the odds of a nursery having existing stooling beds of the proper species and local ecotype are low. Therefore, collecting cuttings and establishing stooling beds should be done early in the planning process so a good supply of cuttings will be available when needed.

Some plants, such as willows and cottonwoods, are either male or female, which can create a serious problem in restoration (Landis and others 2003). If a balanced mixture of male and female plants is not collected from the project site, the resultant stooling beds will not produce both male and female cuttings. When working with dioecious plants, the sexual identity of potential mother plants must be determined prior to collection (See Section 10.2.2, Collecting Wild Cuttings).

Producing Healthy and Vigorous Cuttings **–** One of the most practical advantages of establishing stooling beds in nurseries is that the cuttings are often healthier and more vigorous than those collected from the project site. Willows are host to many insects and fungal pests, such as galls and cankers (Figure 10.72). They are also subject to animal browsing.

Figure 10.71 – *Stooling beds (A) are an efficient way of ensuring that a ready supply of hardwood cuttings of the proper species and source are available (B).*

These factors can significantly lower the quality of wild-collected cuttings. For example, on a riparian restoration project in Idaho, cuttings were collected from heavily browsed willows on the project site and then planted in nursery beds to produce rooted cuttings. The yield of shippable plants was low and these wild-collected cuttings rooted poorly (<50%) when outplanted. These failures increased production costs and threatened the project's replanting schedule. Subsequently, about 150 rooted cuttings from the first nursery crop were used to start a stooling bed. The following year, harvesting just half of the stooling bed yielded more than 6,000 healthy cuttings. Cuttings from the stooling beds rooted at over 99%, thereby lowering establishment costs and keeping the project on schedule (Dumroese and others 1998).

Reducing Costs – It might seem that collecting cuttings in the wild would be the least expensive means of obtaining cutting materials. This is not necessarily the case. Inefficiencies of driving to remote locations, pulling cutting materials to road ways, using make-shift cutting practices, and working under severe winter conditions all add up to high costs per cutting.

10.2.5.3 Select Species Suitable for Stooling Beds

Poplars, cottonwoods, and willows are the species most often used in stooling beds. It should not be assumed, however, that all species of the willow family are good candidates for stooling beds. Some species have growth characteristics that reduce their potential. For example, trials at the Colorado State Forest Service Nursery in Fort Collins have shown that narrowleaf cottonwood (*Populus angustifolia*) and narrowleaf willow (*Salix exigua*) do not "stool" well and must be propagated by other methods (Grubb 2007).

There is great potential for using other woody species that have the propensity to sprout and form roots easily. For example, redosier dogwood (*Cornus sericea*) is commonly grown in stooling blocks and used as a source of cuttings for restoration sites. Outplanting success is higher than with wild cuttings collected on the project site, and has ranged from 50% to 90% (Hoag 2007). In North Dakota, twinberry honeysuckle (*Lonicera involucrata*) is being investigated (Morgenson 2007). Native species that root easily from hardwood cuttings have the potential to be grown in stooling beds to generate cuttings. Species that have inherent deep seed dormancy characteristics, such as snowberry, honeysuckle, elderberry, and some species of currants, could be more easily propagated in the nursery using stooling beds than sowing seeds to produce

Figure 10.72 – *Stooling beds can be cultured to prevent the occurrence of insect galls (A) and fungus cankers, such as* Cytospora *spp (B).*

Table 10.15 – *Native woody plants of the Pacific Northwest with potential for propagation in stooling beds.*

Plant Species		Rooting Ability	Growth Rate	Establishment Success (1 = Poor, 5 = Good)
Scientific Name	**Common Name**			
Baccharis pilularis	Coyotebrush	Fair to Good	Moderate	3
Cornus sericea	Redosier dogwood	Good	Fast	3
Oemleria cerasiformis	Indian plum	Poor to Good	Moderate	1
Physocarpus capitatus	Pacific ninebark	Good to Very Good	Moderate to Fast	4
Philadelphus lewisii	Lewis' mock orange	Fair	Moderate	1
Populus trichocarpa	Black cottonwood	Fair to Very Good	Very Fast	3
Rosa woodsii	Woods' rose	Poor to Fair	Moderate to Fast	1
Salix amygdaloides	Peachleaf willow	Excellent	Very fast	5
Salix exigua	Narrowleaf willow	Very Good	Fast	4
Salix lasiolepis	Arroyo willow	Excellent	Very Fast	5
Salix scouleriana	Scouler's willow	Good to Very Good	Very Fast	4
Spiraea douglasii	Rose spirea	Very Good	Fast	4
Symphoricarpos albus	Common snowberry	Very Good	Fast	4

* = modified from Crowder and Darris (1999)

seedlings. Species that have consistently low seed viability, such as mock orange and ninebark (*Physocarpus* spp.), may also be produced more economically in stooling beds.

The Plant Materials Centers of the USDA Natural Resources Conservation Service identified the potential of a wide variety of woody native plants that would be suitable for stooling beds (Table 10.15). For example, Crowder and Darris (1999) discuss which plants are suitable in the Pacific Northwest and provide a wealth of information on the installation and culture of stooling beds.

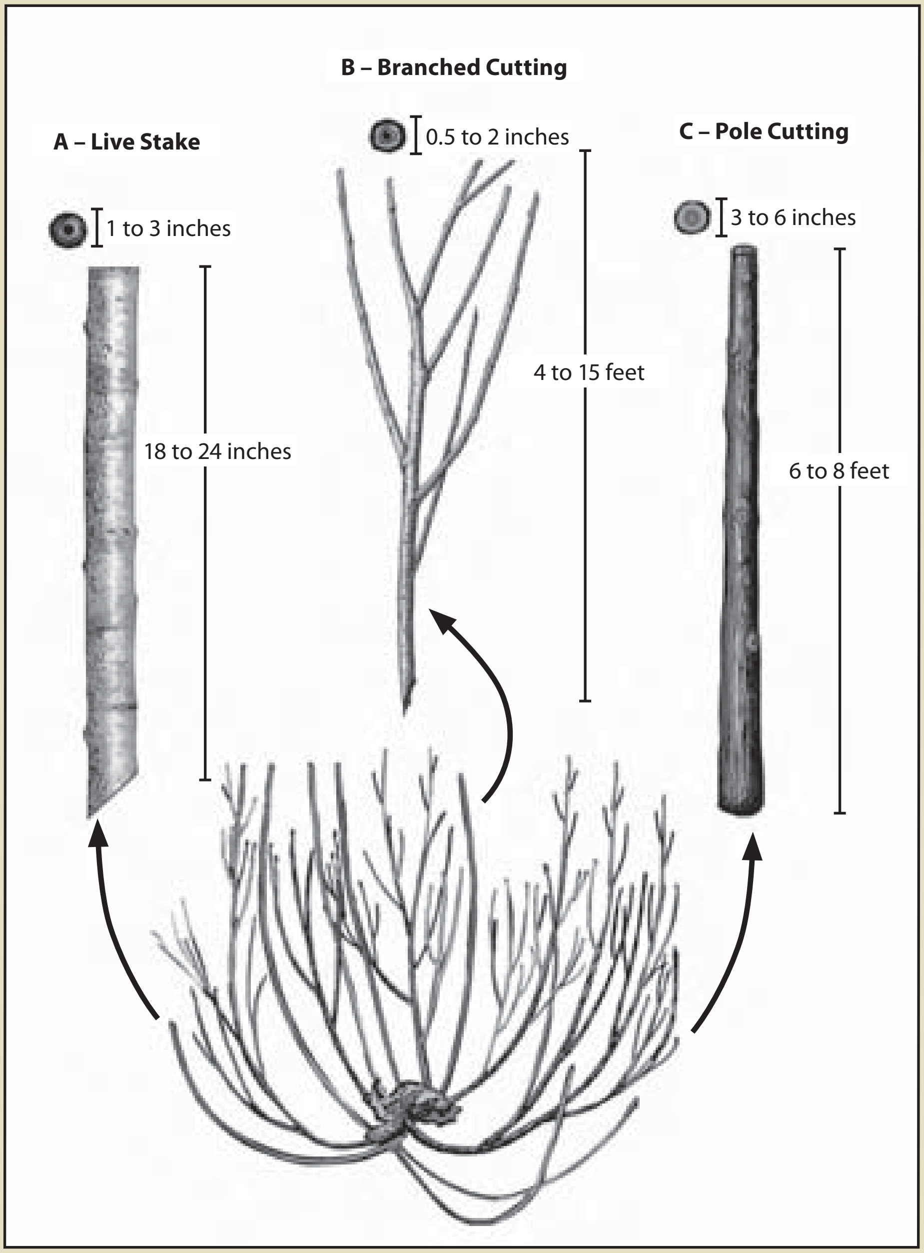
Darris (2002) performed extensive greenhouse and field trials to test the potential of several woody plants for live stake applications. Common snowberry (*Symphoricarpos albus*), salmonberry (*Rubus spectabilis*), Pacific ninebark (*Physocarpus capitatus*), and twinberry honeysuckle (*Lonicera involucrata*) have proven to be effective as live stakes for soil bioengineering in the Pacific Northwest. Notably, several have proven to be superior to willow on some sites, such as salmonberry in wet, shaded environments and snowberry on drier, exposed locations.

10.2.5.4 Select the Type of Cutting Material

Several different types of cutting materials can be collected from stooling beds. Nurseries use small propagation cuttings to start their own bareroot or container plants. Stooling beds can also provide several types of unrooted cuttings used in restoration (Figure 10.73).

Live Stakes **–** Live stakes are so named because, in addition to providing stability on restoration sites, they are expected to root and sprout after installation (See Section 10.3.3.2, Live Stakes). Because they are often pounded into the ground, live stakes are cut from relatively straight

Figure 10.73 **–** *Several types of hardwood cuttings can be obtained from stooling beds, including cuttings for propagation at the nursery or live stakes and branched cuttings for restoration projects. Note that larger plant materials require extra time to produce.*



sections of second- or third-year wood. Live stakes are typically 18 to 24 inches in length and from 1 to 3 inches in diameter (Figure 10.73A). Depending on the plant species, it can take 2 to 4 years for a stooling bed to produce large enough branches for live stakes. Some of the smaller willow species will never grow large enough.

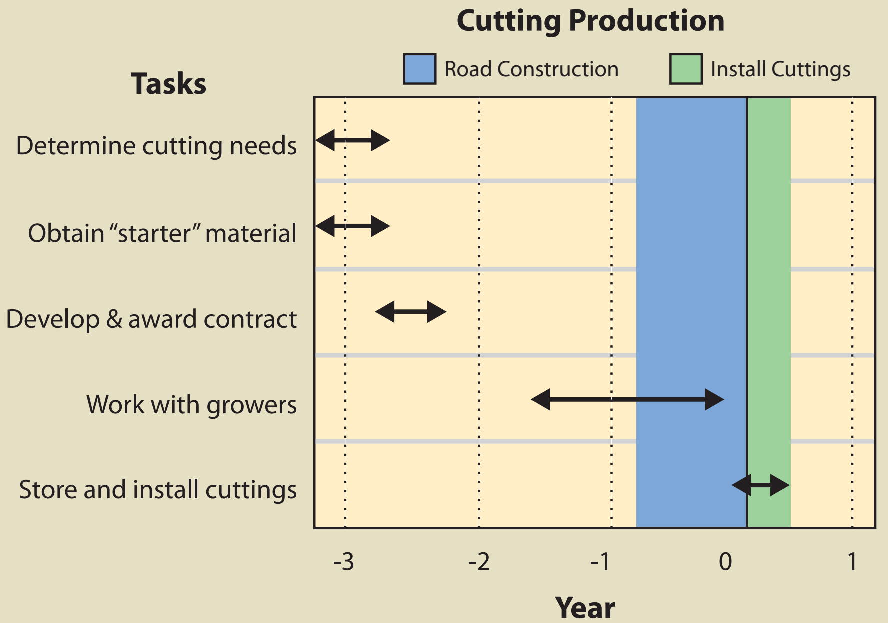
Branched Cuttings – Bioengineering practices, such as live fascines, vertical bundles, brush layers, and pole drains (See Section 10.3.3.3, Live Brush Layers and Section 10.3.3.4, Live Fascines) require a large number of branched hardwood cuttings (Hoag and Landis 2001). The size of this material ranges from 0.5 to 2 inches in stem diameter and 4 to 15 feet in length (Figure 10.73B). Stooling beds may take 2 or more years to produce significant numbers of harvestable branched cuttings.

Pole Cuttings – Pole cuttings (Figure 10.73C) are large diameter (3- to 6-inch) main stems that have all side branches with the top 1 to 2 feet of stem removed. They are used in restoration projects where stability is a main concern. Because of the large size of the plant material necessary for pole cuttings, nursery stooling beds are ideal. Larger trees, such as cottonwoods and tree-sized willows (e.g., Goodding's willow [*Salix gooddingii*]), have primarily been used for pole cuttings. Other large woody plants with the potential to sprout may also prove to be viable material (Dreesen and Harrington 1997).

10.2.5.5 Develop Timeline

Obtaining cutting materials from established stooling beds takes between 1 and 5 years, depending on the type of material. A minimum of one year is necessary to produce branched cuttings; 2 to 4 years to produce live stakes; and pole cutting may require over 4 years (Figure 10.74). In the planning stages of the revegetation project, the number, type, and species of cuttings needed for the project must be determined. Procedures for making these calculations are outlined in Section 10.2.2.6, Determine Cutting Needs. Nurseries or government facilities that specialize in stooling bed production must be contacted to see if they will establish stooling beds for your project. The managers of these facilities will inform you of costs and the time frame for meeting your orders. While there will be some cutting materials produced in the first year, full production of stooling beds does not happen until several years after installation.

Figure 10.74 – *Obtaining cutting materials from stooling beds can take up to four years, depending on the type of material requested. Branched cuttings can be obtained from stooling beds after the first growing season, while live stakes can take from 2 to 4 years. Pole cuttings can take even longer. The following is a timeline for producing branched cuttings and some smaller live stakes. Add several years for large stakes and some poles.*



Most stooling beds are started from cuttings taken from the wild. The sources of starter material must be located in the field during the summer or fall prior to installation of the beds. The sexual identity of dioecious plants must be determined during the appropriate season prior to collection. Section 10.2.2.3, Locate Cutting Areas, gives an outline of the steps necessary to obtain starter material. The nursery managers will tell you the number of feet of starter material, the quality of the wild collections (age, size, condition), and packaging and shipping methods necessary to meet the order. Wild cuttings are collected when the leaves are off the plants. Depending on the climate of the site, collections can begin in mid to late fall and end from late winter to mid spring. Wild cuttings are usually sent immediately to the nursery where they are prepared for installing in stooling beds. Most stooling beds are started directly from cuttings that are stuck in the spring. Cuttings root quickly in the spring and, with irrigation and fertilization, grow into large plants by the end of the summer. The following winter, the beds are ready for harvest. Since stooling beds are relatively uniform, the material can be harvested and processed in a production-oriented manner. Cutting materials are cut to your specifications and stored in either freezer or cold storage facilities until you request delivery.

Developing stooling beds is a long-term investment. While they often take several years to fully establish, stooling beds can remain productive for many years depending on species, ecotype, nursery cultural practices, and pest management. For cottonwoods, stooling beds typically remain productive for 4 to 8 years, after which vigor and productivity start to decline. However, other nurseries have maintained stooling beds of willow and cottonwood for 12 to 15 years without decreases in vigor. *Cytospora* canker, caused by fungi of the genus *Cytospora* spp (Figure 10.72B), is a particularly serious pest of all *Salicaceae* and, because it is transmitted and thrives in wounded stem tissue, can ruin a productive stooling bed. The productivity and longevity of a stooling bed is a direct function of the amount of care given them. Since stooling beds are an investment with long-term payoffs, finding local partners (watershed councils, Forest Service, BLM, state and county land managers), who can utilize these beds after the needs of your project have been met can be a service to the local community.

10.2.6 NURSERY PLANT PRODUCTION

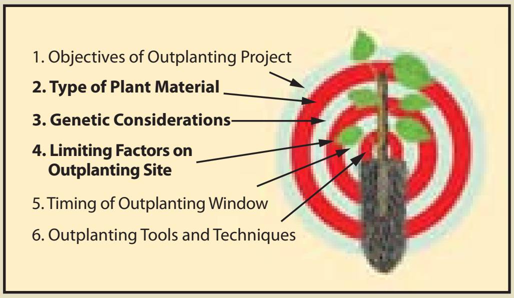
10.2.6.1 Introduction

Woody plants are critically important because they quickly provide vertical structure and aesthetic relief on roadside revegetation projects. When planted within areas seeded with grasses and forbs, trees and shrubs provide the essential matrix of a successful revegetation project. Direct seeding is rarely used to establish woody plants on restoration projects because they are often slow to germinate and take several years to become established. Depending on site characteristics, many sizes of nursery stock can be used, but large plants are favored by revegetation specialists because they establish quickly and dominate the site. Their physical size and deep roots allow them to quickly access deep soil moisture, and their expansive root systems help stabilize soils. In addition to providing wind protection and shade to lower growing vegetation, trees and large shrubs provide habitat for insects, birds, and other animals and can greatly accelerate the development of a sustainable plant community.

Grasses and forbs establish quickly and easily from seeds, so they are not commonly grown in nurseries. However, nursery stock is warranted under certain circumstances:

- Sufficient quantities of grass and forb seeds are rare or hard to collect.
- Increasing grass and forb seeds by seed growers is difficult or excessively expensive.

***Figure 10.75** – Steps 2 through 4 of the Target Plant Concept are very useful when ordering nursery stock (adapted from Landis and Dumroese 2006).*



- Establishing grasses and forbs is difficult on some sites.
- Restoring threatened or sensitive species is a high priority.
- Nursery stock is more effective in restoring wetlands.
- Installing nursery stock is the best and fastest way to achieve a desired plant composition.
- Aggressive weeds are a serious problem.

This guide outlines the steps needed to obtain quality seedlings, transplants, or rooted cuttings from native plant nurseries. Typically, it takes one to two years to grow nursery plants, so the revegetation specialist must develop growing contracts and establish timelines several years in advance.

10.2.6.2 The Target Plant Approach

The target plant concept (Figure 10.75) is one method to optimize the use of native plant materials to ensure successful revegetation of the site. The first two steps in the process were covered during planning (See Section 6.4). Consideration of the plant material that would best meet the project objectives for a given site may lead to the decision to use nursery stock. Nursery stocktype, genetic considerations, and site factors limiting to plant establishment must then be discussed prior to ordering nursery plant materials. These 3 topics will be covered in detail in the following sections. Outplanting windows and outplanting techniques will be discussed in Section 10.3.4, Installing Plants.

***Stocktype* –** The term "stocktype" refers to the various products that a native plant nursery can provide (Inset 10.17). In a broad sense, it includes seeds, which are discussed in Section 10.2.4. The oldest nursery stocktypes are bareroot seedlings and transplants. However, container plants are usually most suitable for roadside revegetation projects. Container nurseries are currently producing a wide variety of stocktypes that include seedlings, transplants, and rooted cuttings. Although project objectives and planting site characteristics should be primary considerations, the choice of container stocktype is more often defined by price. The price of container stock is based on the cost of materials and, more important, nursery production space and time. A unit area of greenhouse bench space or outdoor growing compound is a fixed cost, but the number of months or years to grow the plants to shippable size add to the stock price. Although selling prices for each container stocktype are set by tradition and market factors, older and larger plants will cost more.

***Genetic Considerations* –** Genetics are a key factor in the target plant concept (Figure 10.75), and two factors must be considered: local adaptation, and genetic and sexual diversity.

"Seed source" is an idea familiar to all foresters and restoration specialists. Plants are adapted to local conditions. If native species can be propagated from seeds, these seeds should always be collected within the local "seed zone." The seed zone is a three-dimensional geographic area that is relatively similar in climate and soil type.

Inset 10.17 – Native Plant Nurseries Produce Two Main Stocktypes

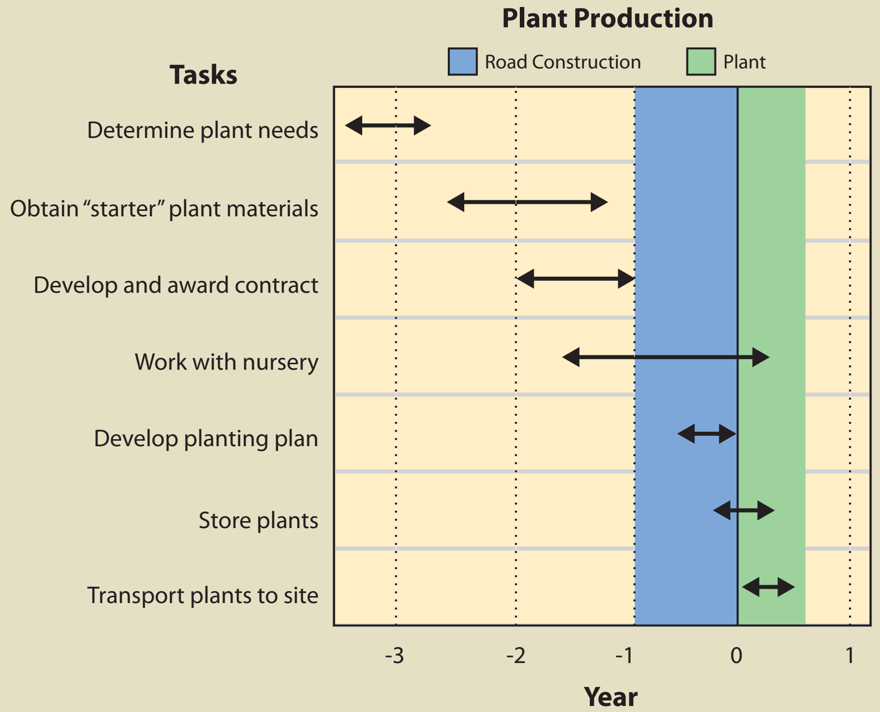
Bareroot stock is grown in native soil in open fields and harvested without soil around the roots. Because of the added care needed and increased potential for transplant shock on highly disturbed sites, bareroot plants are not usually recommended for roadside revegetation.

Container stock is grown in artificial growing media in a controlled environment, such as a greenhouse, and their root systems form cohesive plugs when harvested.

Nursery-grown plants are grown as:

- ***Seedlings*** are plants started from seeds.
- ***Rooted cuttings*** are plants grown from vegetative cuttings.
- ***Transplants*** have been physically removed from the seedbed or container and replanted in a transplant bed or larger container for additional growth.

Figure 10.76 – *Obtaining nursery-grown plants often requires two to three years of advance planning. This timeline can be shorted by up to a year if "starter" plant materials, like willow cuttings or seedlings for transplanting, are available. Certain woody plants require long seed treatments or grow slowly so timetables must be adjusted accordingly.*



Seed source affects plant establishment through growth rate and cold tolerance. In general, plants grown from seeds collected from higher latitudes or elevations will grow slower but tend to be more cold hardy during the winter than those grown from seeds from lower elevations or more southern latitudes (St Clair and Johnson 2003). The majority of seed zone research has focused on conifers in the Pacific Northwest. The same concepts can apply to other native species. Nurseries sow and culture plants according to seed zones. It would therefore be prudent to use nursery seedlings or cuttings from the same geographic zone and elevation in which it will be outplanted.

Target plants should also represent the genetic and sexual diversity present on the outplanting site. To maximize genetic diversity in the nursery plants, seeds and cuttings should be collected from as many different plants as possible. Cuttings must be collected near the outplanting site to assure they are properly adapted. Additional considerations are necessary for dioecious plants, such as *Salix* spp. and *Populus* spp., because all progeny produced by vegetative propagation will have the same sex as the source plant. Therefore, when collecting cuttings at the project site, care must be taken to ensure that male and female plants are equally represented.

Of course, collecting costs must be kept within reason, so the number of seeds or cuttings collected must be a compromise. Guinon (1993) provides an excellent discussion of all factors involved in preserving biodiversity when collecting seeds or cuttings, and suggests a general guideline of 50 to 100 donor plants.

Site Limiting Factors – The fourth aspect of the target plant concept (Figure 10.75) is based on the ecological "principle of limiting factors," which states that any biological process will be limited by that factor present in the least amount. Each planting site must be evaluated to identify the environmental factors most limiting to plant survival and growth (See Chapter 5) as this information is critical to deciding on the proper nursery stocktype. Large container trees with a deep root system typically survive better and establish faster, but woody shrubs and other plants in smaller containers can fill other needs.

Restoration sites pose interesting challenges when evaluating limiting factors. Road construction or decommission typically creates compacted soils that have been severely altered in texture, stability, nutrient status, and so on from their natural state.

In addition to challenging physical soil characteristics, the biological component of roadside planting sites has been severely altered or even destroyed. A variety of mitigating measures may be necessary prior to outplanting. Beneficial soil microorganisms, such as mycorrhizal fungi and nitrogen-fixing bacteria, provide their host plants with many benefits including better water and mineral nutrient uptake. Plants destined for these sites should be inoculated with the appropriate symbiont before outplanting (See Section 10.1.7 for a complete discussion).

10.2.6.3 Develop Timelines

Obtaining some nursery stocktypes can take a considerable amount of lead time and planning. Although most native plant nurseries carry a wide variety of species, it is unlikely they would have plants that are genetically suitable for a specific project. Therefore, "source-identified" native plants must usually be grown by contract. The large nursery stocktypes that will survive and grow on challenging restoration sites typically require several years (Figure 10.76). It is therefore necessary to develop contracts that will assure that the correct genetic material is being propagated and that the resulting plants are of the highest quality that will survive and grow when planted on the revegetation site.

Project plant needs are determined early in the revegetation planning stages, including the number of plants, types of species, and size of plants. From the list of species, seed sources or "starter" plant material sources are located from suppliers or collected in the wild. This can typically take at least a year. Several years before the construction site is ready for planting, a contract for growing plants is developed and awarded. Once awarded, seeds and "starter" plant materials are sent to the nursery so that sowing, transplanting, or sticking can begin promptly.

The growing time for large container stock can extend from 1 to 2 years, depending on the species. The nursery will take a final seedling inventory during the middle of the final growing season. At this time, a planting plan can be developed. Road construction will be moving into its final stage and the planting plan can be tailored to specific on-site conditions. Including lifting, storage, and transporting plant materials, the whole process, from start to finish, takes two to three years.

***Figure 10.77** – A spreadsheet can be used to determine how many plants must be ordered for each species. Each revegetation unit should have separate calculations, since the units will have different survival rates, species mixes, and plant spacing.*

A	Planting area:	0.75	acre	Area that will be planted
B	Target plant spacing:	8	feet	Desired distance between established plants
C	Avg. survival potential:	75	%	Percent of seedlings that survive after one growing season
D	(A * 43,560) / (B * B) =	510	plants	Desired number of established plants after one growing season
E	D * (100 / C) =	681	plants	Number of nursery plants that need to be planted
	Species Mix			
F	Ponderosa pine (PIPO)	50	%	Percent of total established plants composed of PIPO
G	Quaking aspen (POTR5)	30	%	Percent of total established plants composed of POTR5
H	Serviceberry (AMAL2)	20	%	Percent of total established plants composed of AMAL2
I	E * F / 100 =	340	plants	Number of PIPO to order
J	E * G / 100 =	204	plants	Number of POTR5 to order
K	E * H / 100 =	136	plants	Number of AMAL2 to order

10.2.6.4 Determine Plant Needs

Early in the planning stages, a general idea of plant needs is developed based on the desired future condition for each revegetation unit. The information required to determine the quantities for each revegetation unit includes:

- Area to plant,
- Plant spacing (density),
- Survival potential, and
- Species mix.

Using calculations similar to those presented in Figure 10.77, an estimate of the number of seedlings to order from nurseries can be determined. Calculations should be performed for each revegetation unit, since species mix, plant spacing, and survival will change considerably between units.

Planting Area **–** Summarize the acreage of all planting areas within each revegetation unit.

Target Plant Spacing **–** The target plant spacing is the desired distance between established plants. The spacing or density of established plants is an estimate that should be based on the site productivity and project objectives. A review of the reference sites can be a guide to determining the densities and species mix a site will support. Be sure to note how the different plant species are naturally spaced on each reference site. Some grasses and forbs exhibit uniform spacing but many woody plants have a more random or clumped pattern (See Figure 10.119 in Section 10.3.4, Installing Plants, for more discussion).

For example, an undisturbed reference site description shows that an average density for an established stand of trees is 500 trees/ac, with a species mix of 80% ponderosa pine and 20% quaking aspen (Density can be converted to plant spacing by taking the square root of 43,560 divided by plants per acre).The selection of species often determines the planting densities. Shrubs, for instance, grow at much closer spacing than trees, and this should be taken into consideration when species mixes are determined for a revegetation unit.

Revegetation unit objectives often require higher plant densities than typically occur on reference sites. Quick visual screening as the overriding objective will require high-density planting. Selecting a higher plant density than typically occurs in the project area should be done with some projection of how the area will appear many years later. High-density planting can create overstocked stands of trees within ten or twenty years of planting (Figure 10.78). Overly dense stands often lead to stressed trees and high fire hazard conditions, and might require some thinning at a later in time.

Figure 10.78 – *Determining plant spacing should be based on short- and long-term objectives. Where the short-term objective is quick visual screening and site stabilization, high density plantings of 1,500 trees/ac (A) will produce the short-term desired outcome. These trees may need to be thinned to reduce competition to avoid creating an unhealthy stand of trees with a high fire risk. Reducing tree densities to 250 trees per acre will produce a mature stand of trees similar to (B). Planting at these lower densities will reduce the need for thinning, but tree cover will take longer to dominate the site.*

Survival Potential – The survival potential is an estimate of the percentage of planted seedlings that will survive and become established. There are many factors that determine how well nursery-grown plants will survive after outplanting. Factors that you can control include:

- Selection of appropriate species and seed source for the site,
- Quality of nursery plants,
- Appropriate storage and transportation conditions, and
- Care in stock handling and planting.

High rates of plant mortality are usually due to an oversight or neglect of one or more of these factors. Projects with high plant mortality are an indication of poor planning or implementation; in other words, you have missed the mark on one of these factors. However, aiming for 100% survival is often unreasonable because of the high associated costs. Most projects should aim for a plant establishment rate of 85% to 90%, but plan for 75%.

Species Mix – Good survival and establishment of plants fundamentally rests on selecting the most appropriate species from locally adapted seed sources. Selecting the species mix for each revegetation unit should be based on an evaluation of disturbed and undisturbed reference site descriptions, which includes an understanding of the site limiting factors that will affect plant survival.

10.2.6.5 Select Stocktypes

Plants are grown, or cultured, in a variety of ways – indoors or outdoors, in native soil or artificial media, for several months or up to several years. The nursery industry defines how a plant is grown and its size, or morphology, in groups called "stocktypes." Although there is no standard terminology for describing the variety of possible stocktypes (Landis and others 1993), individual stocktypes can be defined by:

- Propagation environment (bareroot or container),
- Years in the nursery, and
- Size or shape of the container for container stock.

Propagation Environment – Plants are grown either in containers (container) or in native soil in open fields (bareroot). Bareroot stocktypes are harvested and packaged without soil around the roots, whereas the root systems of container plants are held together in a plug of rooting media. In many cases, container seedlings can be planted at any time of the year if appropriate

Figure 10.79 *– Native plants have differing growth habits and rates, so it is important to match container size with species growth characteristics. Shaded blocks represent recommended container sizes for each species type in years 1, 2, and 3.*

Container Sizes		Years in Containers									
		1				2				3	
Cubic Inch	Gallon	Evergreen Trees	Deciduous Trees	Shrubs – fast growing	Shrubs – slow growing	Evergreen Trees	Deciduous Trees	Shrubs – fast growing	Shrubs – slow growing	Evergreen Trees	Shrubs – slow growing
10-20		■			■						
30	1/8	■	■	■					■		
60	1/4		■	■					■		
115	1/2		■	■		■			■		
230	1		■			■		■			■
460	2		■			■		■		■	■
925	4						■	■		■	

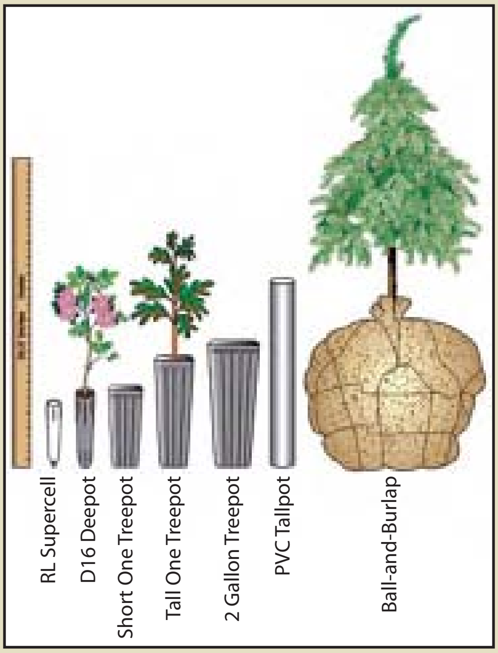
planting methods are used. Bareroot seedlings, on the other hand, are typically lifted in the winter months and held in storage for several months, limiting the planting window from early winter through later spring. Container plants can be grown in large pots for more than two years to very large sizes. Bareroot plants are limited to the depth of the growing beds, which is typically less than 12 inches. Depending on the species, bareroot plants can usually be held in beds for only 1 to 2 years. While container plants have many advantages over bareroots, bareroot seedlings are often much less expensive to purchase and plant. However, for most roadside revegetation sites, we recommend container stock.

Container Size – The size and age of a nursery-grown plant is controlled by the size of the container. Typically, the larger the container, the larger the plant and the longer it takes for roots to fill the container. In Figure 10.79, plants are grouped into broad categories based on how fast they typically fill out various container sizes. Many deciduous tree species, which include willows, cottonwood, maples, alders, and ash, tend to be very fast growing species and can fill out a range of container sizes in just one growing season. Conifer species (firs, pines, cedars, and hemlocks) will fill smaller containers the first year and can be transplanted into larger containers for another one or two growing seasons. Faster-growing shrub species (ceanothus, bitterbrush, mountain mahogany) are often grown in small containers in the spring and transplanted into larger containers several months later. They will fill a 1/8 to 1/2 gallon in one growing season. Slower growing shrub species must remain in the smaller cells for a full growing season before transplanting.

Container Design – Container shape is also an important consideration in stocktype selection because it determines how easily the root plug is extracted from a container, the degree of root spiraling, what planting methods are used, and ease of handling. The depth and taper of the container walls govern how easily a root plug can be extracted from its container. Generally, the greater the taper, the easier a root plug can be extracted from its container. Taper becomes more critical as container walls become longer with respect to the diameter of the opening. Straight-walled "tall pots," made from PVC pipe, are very long in comparison to the diameter of the opening. Root plugs from this container are difficult to extract without the placement of Vexar tubing inside the container. Pulling the Vexar tubing during extraction brings out the entire root plug without undue stress to the stem or root system. Other nurseries offer tall pots with the PVC pipe cut in half lengthwise and held together with electrical ties. Before planting, the ties are cut, which allows easy access to the root system.

Several container design features affect root development and plant quality. When plant roots grow out and hit the sides of the container, they often grow downward in a spiral pattern. When roots reach the bottom holes, they should "air prune." In poorly designed containers, the circling roots will eventually form a tight mesh which, after outplanting, can continue to circle and "strangle" the plant. Most containers have vertical ribs that guide roots down the sides of the container walls to prevent root spiraling. Some smaller containers feature copper coating on their walls to chemically prune the roots as they grow. Other container walls have vertical air slits which air prune the roots. When container roots are so cultured, the root system is more fibrous with more root tips.

Figure 10.80 – *Nurseries can produce plants in all shapes and sizes. The best stocktype for your project will depend on site conditions and time and method of planting.*



Root condition is a critical factor to discuss at the time that growing contracts are being developed. Roots that have excessive spiral growth must be pruned before they are planted (See Figure 10.128 in Section 10.3.4). This is most easily done at the nursery during harvesting. This extra processing step must be stipulated in the growing contract.

Matching Nursery Plants to Outplanting Site – A wide variety of nursery stocktypes are available (Figure 10.80). Site factors should be considered before placing an order. The depth and width of containers are very important for seedling survival and growth. Sites with low precipitation during spring, summer, and fall should be planted with larger container sizes. Where soil moisture-holding capacities are low or vegetative competition for soil moisture is high, long containers should be considered. Where rock content is high and it is hard to excavate a planting hole, shorter container stocktypes should be used. Additional post-planting care must be implemented to compensate for shorter roots (See Section 10.3.4). The planting method dictates the size of the root plug. For instance, the expandable stinger and power augers require plug diameters no greater less than 4 inches. Large seedling stems and tops are required where animal damage is expected.

Stocktype selection often determines seedling survival rates and how fast they grow in the first years after planting. Typically the larger the root system, the better the survival and growth. Larger stocktypes cost more, so it is important to target the stocktype to the needs of the site and revegetation objectives. For instance, if quick establishment of vegetation for visual screening is an important objective, then a large stocktype would be ordered. On the other hand, if a revegetation unit is relatively unseen and the site has few limitations to plant survival, a small, less expensive stocktype would be ordered. While larger stocktypes are generally more expensive than smaller stocktypes, the total costs of establishing seedlings should be considered before settling on a smaller plant. Costs for replanting a site where smaller seedlings died in the first year can be far more expensive than planting larger plants in the first place.

Years in the Nursery – Bareroot stocktypes are often defined by the years they are grown at the nursery, whereas container plants are typically described by the size of the container. This is important when ordering plants because many species take longer than one year to grow to the desired plant size. If plants are needed for a project within one year, the revegetation specialist will need to order smaller size containers to assure that the roots can fill the plug.

Unbalanced or Holdover Stock – A common mistake is growing container plants with tops larger than the root system can support. This is often the result of poor planning, delay of projects, or poor selection of stocktype. For example, road projects are frequently delayed for a year, leaving the revegetation specialist with the problem of what to do about the seedlings

Figure 10.81 *– The shoots of these pine seedlings have grown too large for the size of the root system which increases moisture stress after planting. In addition, the buds have broken dormancy, which means the plants will not tolerate rough handling (A). Poorly balanced or conditioned nursery stock will struggle to survive and grow after planting and exhibit signs of "transplant shock" (B).*

that are being grown. Typically under these circumstances the nursery manager is asked to hold the seedlings in the same containers an extra year. While most will comply, they will do it reluctantly. The result is plants that are "top heavy" – the shoots are too large for the root system to support (Figure 10.81A). The results are often deceiving. The plants have not shown stress because they have been pampered under greenhouse conditions and care. Yet, once seedlings are outplanted on a typical harsh site, it will be a struggle to grow enough roots to keep the tops healthy and alive. Plants respond to the lack of moisture in what is referred to as "transplant shock" (Figure 10.81B) by shutting down growth and often turning yellow or "chlorotic." Roadsides are stressful sites that require the very best quality plant material. A good example of the difference between well-balanced and poorly-balanced nursery stock is shown in Figure 10.82.

Delays are common in roadside projects, so two viable options can be considered: 1) transplant the stock into larger containers, 2) reject the plants and place a new order. Option one is appropriate if the plants are being grown in small containers and a larger container is available for transplanting. If you are growing plants in a large container, it makes little sense to transplant into a still larger one. This option is often more costly than option two, which is simply starting over with the order. But starting over assumes available seeds and other starter plant materials, and enough time to reorder. And what can be done with the plants that are not being used? You or the nursery manager can contact land managing agencies and landowners in the general geographic area to see if they are interested in these plants. If they are not, there are often watershed councils or environmental groups that would appreciate the donation for their projects.

10.2.6.6 Obtain Seeds or Other Starter Plant Materials

Nursery-grown plants begin from source-identified seeds or other "starter" plant materials (cuttings, smaller seedlings for transplants) that must be supplied at the beginning of the

Figure 10.82 – *The ponderosa pine seedling in the photograph (A) was grown for four or five years at a nursery and outplanted on a semi-arid site. The photograph was taken one year after outplanting and shows the seedling has undergone transplant shock due to the imbalance, or high shoot to root ratio, of the seedling when it was planted. The seedling was root-bound when it was planted. The tree responded by dropping most of its nursery needles and grew very little in height in the first year. Photograph B shows a ponderosa pine seedling that was grown in a one-gallon container for one year, then outplanted. Because this seedling had good balance and was not root-bound, it did not undergo transplant shock after it was outplanted. After two years, this seedling is well established. The brackets in both A and B show the current year leader growth.*

contract (Figure 10.83). Since starter plant materials can take a year or more to obtain, it is important that these needs are identified early in planning, and collection contracts are put into place as soon as possible. Locally adapted seeds of some trees can take years to obtain because some species do not produce a crop every year. The benefits and drawbacks of each type of starter plant material are discussed below.

***Seeds* –** Starting plants from seeds is usually the least expensive method of plant propagation and offers the greatest genetic diversity. The downside is that, for most species, seed propagation is slower than growing from cuttings or transplants. Crop production times will vary with species and nursery practices. Most woody plants take two to three years to grow into large plants from seeds and must be transplanted at least once. Other faster-growing species can reach shippable size in one growing season with good culture.

Seeds are either collected in the wild by seed collectors, or field-grown in an agricultural setting from tree and shrub seed orchards or from grass and forb seedbeds (See Section 10.2.4). Both wild-collected and field-grown seeds are sometimes available from federal seed extractories, federal nurseries, Forest Service district offices, or BLM resource areas. These agencies usually have tree seeds for most seed zones that cover federal lands, and often some selection of shrub, grass, and forb seeds are available. It is worth checking to see if these sources are available before you decide to collect seeds from the wild. Seed dealers do carry inventories, so be sure to inquire as to species and collection source. The single best resource for seeds or nursery stock is the Plant Materials Directory, which is published yearly as a special issue of the Native Plants Journal:

Indiana University Press
Journals Department
601 N Morton Street
Bloomington, IN 47404-3797
TEL: 800.842.6796
Website: http://www.nativeplantnetwork.org

Seeds obtained through federal facilities or seed dealers must report: 1) seed source – location of collection or seed zone; 2) year of collection; 3) seeds per pound; 4) % purity; 5) % germination, or tetrazolium (TZ) tests, from recent testing facilities; and 6) amount of noxious weed or other non-crop seeds. If seeds are not available through either of these sources, wild seed collection will be necessary. This can be done under the direction of district or forest botanist or by contract.

Once a plant production contract is awarded, nurseries will request information on each of the seedlots they will be sowing, including the latest purity and germination test results to determine the amount of pure live seeds. In addition, they will require the number of seeds per pound to calculate how many pounds of seeds from each seedlot will be needed to meet your order. They will also factor in the difficulty of growing each species, called the nursery factor, which will be different for each species, stocktype, and nursery. The nursery factor is a prediction of what percentage of seeds sown will become "shippable" seedlings, and considers losses during the growing season as well as those plants which are "culled" during harvesting. Nursery factors typically range from 30% to 50%, which means that they will need to sow 2 to 3 viable seeds for each plant they produce.

You can get a rough idea of how many seeds should be acquired by using the seed tests and a nursery factor of 30%. If the nursery requests significantly more seeds, then it is appropriate to inquire why more seeds are needed.

***Starter Plants* –** Most large container stocktypes are started by moving smaller plants into larger containers

***Figure 10.83** – Nursery grown plants are propagated from source-identified seeds or other starter plant materials. Usually, seeds or starter materials must be secured prior to the award of a plant production contract.*

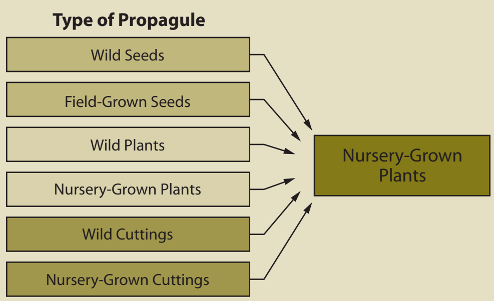
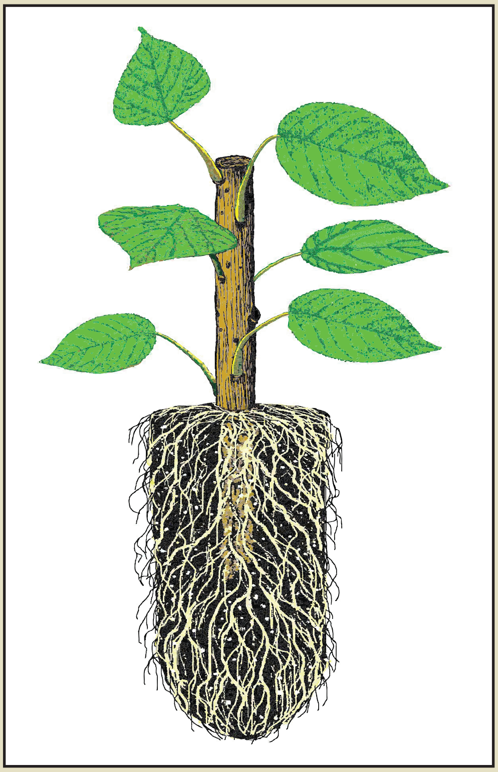


Figure 10.84 – Rooted cuttings are the quickest and easiest way to produce some woody plants, such as cottonwoods and willows.



or into bareroot growing beds. This practice is called transplanting, and it produces quality plants with large, fibrous, healthy root systems and large stems. Starter plants are typically grown from seeds or cuttings into small plants and then transplanted. In some cases, wildlings can be salvaged from the construction site and brought back to the nursery for transplanting. When ordering large containers, it should be specified that there will be at least one, and sometimes two, transplanting operations. Growing starter plants large enough for transplanting usually takes a year. They are then transplanted, usually in the spring or fall, and grown for another year or two. If seedlings or rooted cuttings are available from other sources, these can be sent directly to the nursery for transplanting, which would decrease production time by a year.

Rooted Cuttings – Rooted cuttings (Figure 10.84) can be shipped directly from the nursery for outplanting or serve as starter plant material for transplanting into larger containers. One big advantage of this stocktype is that cuttings can be collected each year, whereas seeds may be more difficult to procure. While cuttings of most species are derived from stems or branches, some species like, quaking aspen (*Populus tremuloides*) must be started from roots. Rooted cutting production is discussed in detail in Section 10.2.5.

10.2.6.7 Develop Growing Contract

All nurseries experience weather extremes, insect or disease losses, equipment failures, and other production problems that can severely decrease the quantity and quality of the stock. Therefore, it is a good strategy to reduce these inherent risks by growing plants at more than one nursery. In doing this, you will begin to see the strengths and weaknesses of each nursery. Future ordering can use this information to decide where to grow each species.

Nursery Selection – The western United States has an abundance of nurseries that grow native plants, but few will offer plants from source identified plant materials specific to your project. Obtaining genetically appropriate plants will require finding nurseries willing to grow seedlings from specified genetic material. A current list of native plant nurseries can be found in the Plant Materials Directory (See Section 10.2.6.6).

When considering a nursery for plant production, there are some basic factors to consider:

- ***Proximity.*** Is the nursery close enough to visit occasionally?
- ***Service.*** Is the staff easy to contact? Do they promptly return phone calls or e-mails? Are they friendly and helpful?
- ***Expertise.*** Are they knowledgeable in restoration and revegetation?
- ***Years in business.*** Has the nursery been in business for at least 3 years?
- ***Seedling quality.*** Is the overall seedling quality high?
- ***Seedling quantities.*** Are the orders regularly met or do they consistently run short?

- ***Price.*** Are prices competitive?
- ***Willingness.*** Will the nursery try new things?

If there are doubts about one or more of these factors, you might consider growing at another nursery. Ultimately, the selection comes down to personal experience with nurseries and word-of-mouth from other revegetation specialists.

Seedling Orders – A plant production contract must detail the information you have developed in previous sections of this chapter:

- Species,
- Genetic source,
- Starter plant material,
- Stocktype,
- Net amount of plants,
- Month and year for plant delivery,
- Minimum seedling specifications, and
- How they will be processed and stored.

A few phone calls to nurseries will give you some idea which ones will grow the species, stocktype, and quantities necessary for your project. Nurseries can still be utilized if they can only meet a portion of the order. Other nurseries can produce the remainder because there is less risk by sending plant orders to several nurseries. Contracts can be developed once you have some idea of what portions of an order a nursery can produce.

Plant Processing and Storage – Once seedlings have reached the target size and age at the nursery, they are harvested, stored, and processed for shipping. If the plants are bareroot seedlings, they are lifted from the soil, graded, and packaged. Container seedlings can be extracted from the containers, graded, and packaged, or sent to the planting site in containers and extracted immediately before planting. Either way, most stocktypes will be held at the nursery for one to six months, depending on when they are needed for planting. "Planting windows" are discussed in more detail in Section 10.3.4.

Storage times are longest for seedlings planted in the late winter and spring. For these orders, plants are extracted from their containers or lifted from the soil in the winter when they are least susceptible to the stress or damage associated with extraction, handling, and packaging. Plants in this condition are dormant. The onset of plant dormancy for deciduous plants is often around the time when plants have lost their leaves in late fall; the end of dormancy begins just before the buds begin to swell in the late winter to spring. The dormancy period for conifer species is not visibly discernible, but typically follows a similar time frame as deciduous species. Seedling dormancy in the western United States typically extends from December through February, but the dates will vary by nursery. If plants are to be extracted and held in cold storage for long periods, it is important to known when the nursery is extracting and handling the seedlings to be sure these operations are done when seedlings are dormant. Seedlings that are extracted or lifted outside the seedling dormancy period and stored for any length of time will survive and perform poorly.

When plants are lifted from bareroot beds or extracted from containers, they are also being graded for size and appearance. Unless otherwise agreed, the size specifications stated in the contract will be the grading criteria (Figure 10.85). It is good to be at the nursery during lifting/extraction and grading to see which seedlings are being thrown away and which seedlings are considered shippable. Bareroot and smaller container plants are graded and boxed for refrigerated or freezer storage. Storage containers will have important information about the plants, such as seedlot, date packed, client name, and the number of seedlings in the container. Plants are typically held in cooler storage (32 to 35 °F) from a few weeks to two months. If longer storage is required, freezer storage (28 to 31 °F) is recommended to maintain seedling quality and reduce the chance for storage molds.

Large container stocktypes (typically those equivalent to a half gallon or larger) are stored and transported in the containers in which they are grown. They are typically stored in shadehouses or other sheltered storage. In cold climates, the roots should be insulated to protect against

Inset 10.18 – Assessing Poor Quality Nursery Stock

Poor quality planting stock can be caused by biotic (e.g., diseases, insects) or abiotic factors (e.g., imbalance of soil moisture, temperature, nutrients, and pesticides) in the nursery resulting in detrimental, and sometimes devastating, effects on seedling survival and growth when outplanted. Infection with various pathogens, or biotic causes, may not necessarily be manifested in a nursery, but may cause stunting or mortality once seedlings are under stress following outplanting. Revegetation specialists should be aware of the possible nursery diseases in order to either recognize or discuss with nursery personnel during visits to inspect their seedlings.

Diseases caused by fungi, water molds, bacteria, and viruses can often be difficult to distinguish from damage caused by abiotic events or factors. If damage or chlorosis of seedlings is noted, it is recommended to check with the nursery manager to determine the history of the seedlings, what pathogens are traditionally a problem at the nursery, and what, if any, have occurred during the current growing season. Hamm and others (1990) and Landis and others (1990) provide more detailed information on nursery pests.

Shoot and foliage diseases can be caused by a variety of organisms, with various levels of impact on seedlings. Fusarium hypocotyl rot (caused by *Fusarium oxysporum*) can cause large losses in the nursery from July through October. Gray mold (caused by *Botrytis cinerea*) can cause significant damage to densely grown bareroot and container seedlings, as well as nursery stock stored in less than optimal conditions (Hamm and others 1990). The mycelium and gray spore clusters are often easily visible to the naked eye. Botrytis can girdle infected seedlings, increasing mortality rates following outplanting. Minor shoot and foliage diseases, such as shoot blight (caused a number of organisms including *Sirococcus* spp., *Phomopsis* spp., and *Phoma* spp).and needle-casts and other foliage diseases tend to deform or stunt seedlings, but do not result in significant mortality in the nursery or in an outplanting situation.

Root diseases may be the most insidious of nursery seedling diseases. Since seedlings are cultured under optimum conditions for growth, symptoms are often masked throughout the growing season, manifested only during outplanting stress or drought stress in succeeding years. Most conifers, and many native species, are susceptible to root diseases and root rots caused by *Phytophthora* spp., *Fusarium* spp., and *Cylindrocarpon* spp. These diseases will be manifested in the nursery in pockets of symptomatic seedlings or mortality, particularly in areas of poor drainage or previous infestation. Outplanting seedlings infected with these pathogens will result in reduced survival. In addition, transfer of these organisms to outplanting sites may result in infection of the planting area. This specifically is a problem with the root disease, *Phytophthora lateralis*. The spread of this disease from infected seedlings can devastate populations of established Port Orford cedar.

Not all seedling quality problems are caused by biotic factors – many are one-time damaging events that occur during a short time span with a regular distribution throughout the field or greenhouse (Mallams 2006). If foliage discoloration, foliage or stem wilting or die-back, seedling stunting, or mortality occur in large patches or over large areas in the nursery, the causes are often abiotic. Outplanting seedlings that have been stunted or damaged in the nursery can reduce seedling growth and survival, as well as increase the time required for site recovery. However, the symptoms of abiotic damage are often more apparent, and the consequences more easily predictable, than damage caused by pathogens.

Although restoration personnel have little to do with nursery cultural practices and disease mitigation in the nursery, several options exist to prevent or control disease problems on restoration sites. Disease mitigating measures are similar to insect mitigating measures: 1) only plant healthy stock because weakened or stressed seedlings are more susceptible to diseases both in the nursery and on the outplanting site, 2) plant a variety of species to avoid outplanting failure due to infestation of any single disease, 3) create a healthy soil environment – seedlings grown on poor sites or on sites outside of the species environmental ranges will be placed under stress and more susceptible to disease infection.

cold injury. During unseasonably warm periods during the late winter or early spring, large container stock should be monitored for drying and irrigated if necessary.

Grading Specifications – There are no nursery-wide minimum nursery standards for the size and appearance of nursery grown plants because of the wide variety of ages, stocktypes, and growth patterns of native species. Nevertheless, you must establish some criteria for accepting or rejecting plants or you might be receiving marginal plants. Being present at the time of packing is the most effective way to negotiate grading standards with the nursery and assure that you receive quality plants.

Typical grading standards fall into the following categories (Figure 10.85):

Stem diameter at root collar ("caliper") – Stem caliper is the single most important morphological measure of nursery plant quality and has been consistently correlated with outplanting survival and growth. Diameter is not necessarily a good measurement for rooted cuttings since the size of the stem is dependent on the original diameter of the cutting. A typical grading specification for many bareroot and container stocktypes is a minimum diameter of 3.5 to 4.0 mm for one-year-old seedlings, and greater than 4.0 mm for plants grown for two years. Discuss these specifications with the nursery, since not all species will grow to these sizes in this time frame.

Shoot height – The height of the plant is measured from the root collar, or original ground line, to the top of the terminal bud. Some species do not form a terminal bud, so the swollen meristem tip or even the average top of the crown is used.

Root system – The root system of the plant should be examined carefully. For bareroot stock, the roots should be well developed and fibrous and approximately the same area as the crown. For container stock, the root "plug" must be firm but not too root-bound. If the roots have spiraled and formed a tight mass at the bottom of the plugs, they should be trimmed during harvesting.

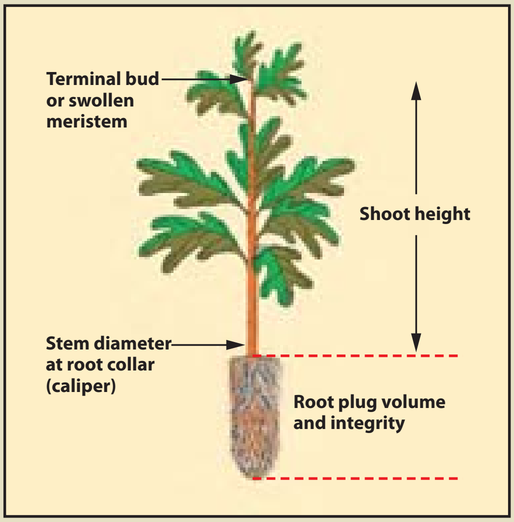
Seedling Balance – Nursery stock should have a good ratio between the amount of foliage and the root system. This is traditionally expressed as a shoot-to-root ratio (S:R), and typically ranges from one or two part shoots to one part roots (an S:R from 1:1 to 2:1). This grading standard is a qualitative determination to whether the root system is large enough to support the above-ground portion of the plant.

General plant health – During grading, nursery stock should be inspected for physical injury or disease. Root disease is a particular hazard of container stock, and soft or moldy roots should be suspect. Scraping the roots with the blade of a knife should reveal white healthy tissue.

10.2.6.8 Administer Contract

The nursery manager should be required to maintain records on how the plants were cultured. The basic information should include: date plants were started; the type, rates, and timing of fertilizer applications; irrigation schedules; greenhouse settings (temperature, lighting,

Figure 10.85 – *Grading criteria for seedlings are based primarily on stem diameter, height, terminal bud, root volume, and integrity.*



humidity); pesticide applications; and any significant problems that might have occurred with the seedlot. The nursery is also required to give an accounting, or inventory, of your plant orders by late summer.

It is important to visit nurseries at least once a year, but more often is better. These visits will give you an indication of the quality of the stock you will be receiving and whether the number of seedlings you ordered is being met. It also helps strengthen the relationship between you and the nursery manager, which often leads to more attention being given to your orders. One of the best times to visit is during the initial plant establishment phase, which is during the late spring or early summer after seeds have germinated or seedlings and cuttings have been planted. If there are stock problems, they are most likely to be observed at this time. If for some reason there is a fall-down in the inventory or the seedlings look unhealthy at this time, you have an opportunity to discuss it with the nursery manager. If caught early enough, there can be time to start more plants. At the minimum, identifying problems early will give you time to adjust your planting plans as well as adjust other contracts that depend on the plant inventory.

Another good time to visit is during the processing of plants for storage or shipment. Your presence at this time helps the nursery manager with questions that might arise about grading specifications, packaging materials, pruning, and other operations that occur at this time. It gives you a good picture of what type of stock you will be receiving when it is shipped to the planting areas. It is never an enjoyable experience to open up a box of seedlings, with planters standing around, and be surprised to find that the seedlings are not at all what you were expecting.

10.3 INSTALLING PLANT MATERIALS

Once the project site has been prepared (See Section 10.1, Soil and Site Treatments) and the plant materials have been obtained (See Section 10.2, Obtaining Plant Materials), the vegetation can be installed on the project site. The following implementation guides cover the methods for installing seeds, cuttings, and plants. Section 10.3.1, Seeding, discusses the different methods of seeding, how to formulate seed mixes, determining seeding rates, and assuring quality. A specialized form of seeding, hydroseeding, is discussed in Section 10.3.2. Section 10.3.3, Installing Cuttings, outlines cutting installation techniques most commonly used in biotechnical engineering designs. Section 10.3.4, Installing Plants, discusses techniques for planting bareroot and container plants. It also discusses seedlings, plant handling, storage, and quality control measures.

10.3.1 SEEDING

10.3.1.1 Introduction

Seeding is the distribution of seeds for the purpose of establishing seedlings at a desired density and species composition. Optimal seeding operations must take into consideration: 1) how seeds are uniformly distributed over an area, 2) where seeds are placed vertically (that is, in, on, or under the soil surface), 3) species composition in the seed mix, and 4) when seeding takes place. These factors must be adapted to each revegetation unit to account for the unique climate, soils, and species requirements of each site.

Seeding is often coupled with other operations, such as fertilization, soil amendment applications, and soil stabilization treatments. While accomplishing these objectives at the same time as seeding often makes practical sense from an economic and scheduling standpoint, it might not always be best for the short-term establishment of native vegetation. It is important to consider the effects of combining too many operations into the actual sowing operation. It may be necessary to plan some of these operations at different times. For example, fertilizing, which is often done during the seeding operation, might best meet objectives if applied separately from seeding (See Section 10.1.1).

This section will cover the different steps in developing a seeding plan: 1) identifying seeding areas, 2) determining seed application methods, 3) developing seed mixes, 4) determining sowing rates, 5) preparing seed mixes, 6) selecting sowing dates, and 7) applying seed and assuring quality.

10.3.1.2 Identify Seeding Areas

It is important to visit the project site as soon after road construction as possible and specifically identify seeding areas on the ground. If road construction is a multi-year project, finished slopes should be assessed for seeding while the remaining construction continues. While most of the seeding areas will conform to the revegetation units developed during planning, sites always look different after construction. A field review should note where topsoil has been placed, presence of surface rock, surface roughness, accessibility by equipment, microclimate, soil compaction and other site factors. These factors will be used to develop: 1) seeding methods, 2) sowing dates, 3) seed mixes, and 4) seeding rates for each of the seeding areas.

Seeding areas are located on a map and by road station. For each seeding area, acreage can be calculated using methods described in Figure 9.2 in Chapter 9, Implementation. These calculations must consider the areas where seeding will actually take place. For instance, seeds should not be applied in areas where herbicides will be used for maintenance. At the end of the field survey, total acreage for each seeding area will be summarized and this information will be used in developing seed mixes for each seeding area (See Section 10.3.1.6 and Section 10.3.1.7).

10.3.1.3 Determine Seeding Methods

There are a variety of methods for applying seeds available to the revegetation specialist. The challenge is matching these methods to the sites encountered in mountainous terrain. Typically, the site characteristics of each seeding area will dictate the type of seeding method used. For example, a road project has three revegetation units – a steep, north-facing slope; an obliterated road; and a rocky south slope. Hydroseeding could be planned for the steep, north-facing slope where other equipment cannot reach. On the obliterated road, several ground based seeding methods could be used, including mixing seeds into the soil, or broadcasting on the surface and covering with a mulch. The south-facing slopes could be hand-seeded or hydroseeded, then covered by a mulch to keep the seeds from drying out during germination. Each project needs to approach seeding with a strategy that is the most efficient and will provide optimal conditions for seed germination.

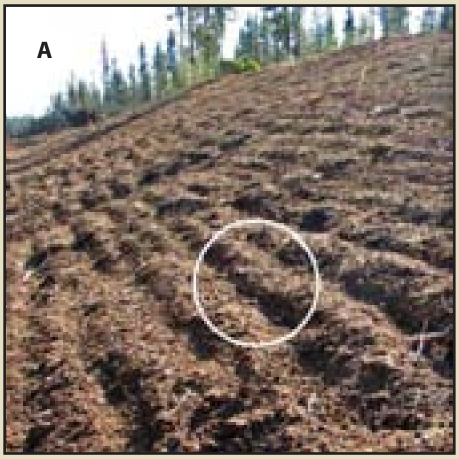
Each species has a unique seed covering requirement. While seeds of most species must be buried in the soil or covered by mulch to germinate, some species actually require some exposure to light to germinate and must not be covered very deeply. A general rule for seed covering is to bury seeds at depths from twice (Munshower 1994) to three times (Monsen and Stevens 2004) the seed diameter. The deeper the seeds are covered, the less likely they will dry out during germination. The tradeoff, however, is that seedlings will have to expend more energy to emerge from deeply buried seeds. This can ultimately affect early seedling establishment.

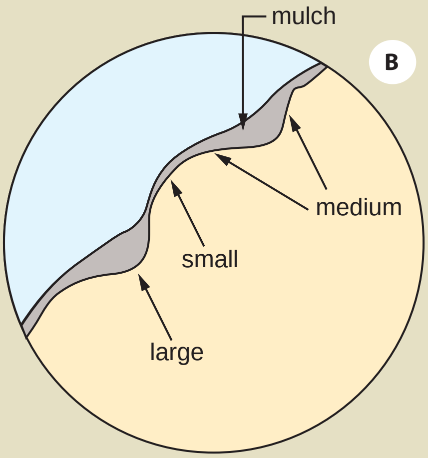
The ideal seedbed, as defined by Monsen and Stevens (2004), is "one in which the seed is firmly enclosed within soil particles to provide hydraulic conductivity of moisture to the seed. Seeds should be placed deep enough to prevent rapid drying but shallow enough to allow natural emergence." Creating an ideal seed environment is an important practice, especially in nurseries, farms, or gardens where the objective is to create a uniform plant crop. All operations in these settings must be standardized and uniform (e.g., correct seed depth, optimum lighting, uniform irrigation, uniform seed densities, etc.). While uniformity and standardization can be applied to wildland revegetation, an alternative strategy might be considered. This strategy starts from the premise that we really cannot know much about the specific germination and early seedling growth requirements of different native species at each seeding site. For this reason, we should be creating a variety of environments, or "regeneration niches" (Grubb 1977), where seeds might find the right conditions for germination (Figure 10.86). Further, we should apply a range of native species to fill these environments. With wildland revegetation, uniformity is not the objective. In fact, non-uniformity will most likely fit with the surrounding plant communities.

Vertical seed placement, where seeds are vertically distributed in soil or mulch layers, can be grouped into the following categories:

- Broadcast onto the surface,
- Pressed into the soil surface,
- Mixed under the soil surface,

Figure 10.86 *– When a seed mix, ranging from small to large seeds, is applied to an uneven surface (A) and covered by a long-fibered mulch (B), a range of germination environments are created. Optimum germination environments for large seeds occur in depressions where deeper seed cover occurs; optimum germination environments for small seeds, needing less cover, occur on the ridges where mulch is not as thick.*





- Drilled under the soil surface,
- Covered with long-fiber mulch,
- Mixed into long-fiber mulch, and
- Mixed into hydromulch.

Vertical seed placement methods will be discussed in the following sections in the context of how they affect germination and seedling establishment.

Seeds Sown on the Soil Surface **–** One of the most common forms of seeding is broadcast seeding, which is casting seeds on the surface of the soil with a rotary spreader or by hand. Broadcast seeding is almost always the least expensive form of seeding. Rotary spreaders can be attached to most types of vehicles, including all-terrain vehicles and pickups, and used where vehicle accessibility is good. Where slope gradient or accessibility limits mechanical seeding, using a hand-held broadcast seeder is an option. While manual broadcast seeding might be considered a very low-tech method, it still has an important place in revegetation.

Manual broadcast seeding offers the opportunity to spot-seed microsites at different seed rates and seed mixes. For example, two people could hand seed a steep cut slope requiring two different seed mixes – the lower portion of the slope sown with a grass and forb seed mix and the upper portion with a shrub and seed mix. In another instance, a fill slope composed of rocky outcrops interspersed among deep soils has two distinct microsites that could be seeded separately with different seed mixes. With knowledge of the road objectives, several hand seeders can apply seeds across a project area that mimics the vegetative patterns of the landscape. Spot-seeding can also be a method of applying valuable seeds or "unique" species to strategic locations. For instance, showy forbs that are expensive to obtain or require a specific habitat can be spot-seeded in those locations.

The disadvantage of broadcast seeding is that seeds are not covered by soil or mulch (Figure 10.87). Since seeds need intimate contact with the soil to germinate, broadcast seeding typically leads to low establishment of seedlings. If greater quantities of seeds are sown; however, some seeds will find microsites with high humidity (between surface gravels or rock) or will be covered by soil particles that have been moved through erosion processes. Estimates of 50% to 75% more seeds must be sown to compensate for the inability of seeds to germinate or the loss of seeds to rodents (Monsen and Stevens 2004). Survival factors must be adjusted downward when calculating sowing rates for seed mixes (See Section 10.3.1.6). Broadcast seeding on roughened surfaces can potentially increase germination rates, especially if seeds are sown in the fall. The probability that seeds will be covered by sloughing soil over time is increased (Stevens and Monsen 2004), so it is important that the soil surface be left as rough as possible where broadcast seeding will be used.

Seeds Pressed into the Soil Surface **–** Seed that is sown on the surface and pressed into the soil increases germination rates over broadcast sowing. Seeds are in firm, intimate contact with the soil, which increases available water to the seeds (Stevens and Van Epps 1984) (Figure 10.88). Imprinting produces a variety of microsites which may benefit the germination of a mix of species (Stevens and Monsen 2004). This type of seeding is accomplished with imprinting equipment (See Section 10.1.2.4). In this operation, seeds are dropped from a seeder mounted in front of the imprinter and then pressed into the soil. Imprinting works well for small to medium sized seeds; seeds are in firm contact with the soil but not buried too deeply to affect seedling emergence. In some cases, imprinting small- and medium-sized seeds can result in germination

Figure 10.87– *Broadcast seeding leaves seeds exposed on the soil surface where they are not in contact with the soil.*

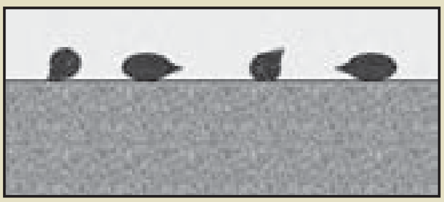
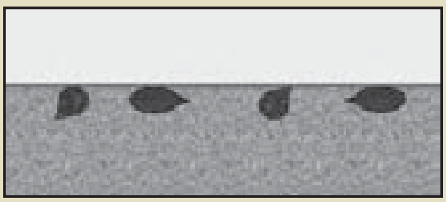
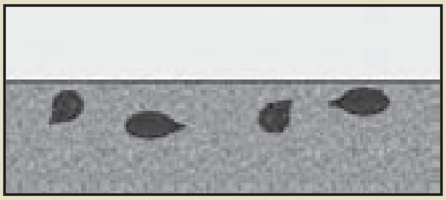


Figure 10.88 – *Pressing seeds into the soil surface improves germination by increasing soil contact.*



as good as, or better, than drilling seed (Haferkamp and others 1985). Larger seeds must be covered by soil or mulch for adequate germination. Imprinting seeds cannot occur on steep slope gradients or slopes with high rock content. Sites that are too steep for tractor access are too steep for current imprinting equipment.

***Figure 10.89** – Seeds mixed under the soil surface puts them in direct contact with the soil, greatly improving germination.*



Seeds Mixed Under the Soil Surface – Mixing seeds into the surface of the soil is one of the best ways to achieve optimum germination (Figure 10.89). Mixing is done in two stages – seeds are applied on the soil surface by either broadcast seeders or by using a seedbox and drop tubes; seeds are then incorporated into the soil by dragging anchor chains, disk chains, cables, pipe harrows, or other implements behind a tractor. Equipment has been developed for wildland conditions that will seed and incorporate in one operation. The "ripper-seeder-harrow" (Figure 10.90) is a specialized seeder that subsoils, broadcasts seeds, and mixes in one operation. Use of this equipment is limited to slope gradients of 3H:1V or less and non-rocky soil surfaces.

When mixing seeds into the soil on steeper slopes, any method that scarifies the soil surface after seeds have been broadcast will mix the seeds into the surface. Using a hand rake to incorporate broadcast seeds into the surface works well, and can be used in areas where expensive or valuable seeds have been applied. This type of seed placement requires that the seed depth be monitored to assure that it is not buried too deeply. Seeds should not be mixed deeper than one inch.

These application methods allow seeds to be mixed evenly through the soil and not concentrated in rows, as they are with drilling (see below). However, soil is left loose around the seeds, which decreases water-holding capacity. If seeds are sown in the fall and do not germinate until the following spring, natural packing of soil around the seeds will occur.

Seeds Drilled Under the Soil Surface – Using a seed drill is another method for covering seeds with soil. Seeds are not actually drilled into the soil, as the name implies, but sown just under the surface in rows. Seed drills 1) open the surface of the soil with a disk or tine; 2) drop seeds from a seedbox, through tubes, into the open furrows; 3) close the furrows with a disk; and 4) pack the soil firmly around seeds with a press wheel. Cropland drills have been developed for the agricultural industry. However, this equipment has limited applicability on highly disturbed sites because rocky soils and uneven soil surfaces create difficulties in placing seeds at proper soil depths. Several drills have been developed for rangeland restoration that compensate for these limitations. The Rangeland and Truax® drills were specifically developed for seeding rocky, uneven surfaces. The Truax® drill was an improvement on the Rangeland drill, and includes

***Figure 10.90** – The "ripper-seeder-harrow" equipment was developed by the Umatilla National Forest. This equipment prepares the soil surface and mixes the seeds into the surface in one operation. Soils are loosened using subsoil tines, leaving a roughened soil surface (A). Seeds are metered from a seedbox through drop tubes onto the soil (B), where seeds are mixed into the soil using a chain harrow (C). Blueprints for this equipment can be obtained from the USDA Forest Service, Missoula Technology Development Center (MTDC).*

Figure 10.91 – Seed sowing and mixing equipment can be attached to most types of ground based equipment, including all-terrain vehicles. A seed spreader attached to the back of an all-terrain vehicle broadcasts seeds on the soil surface and a chain harrow mixes seeds into the soil.

three seed boxes that can independently distribute seeds at different depths corresponding to the size and shape of the seeds (Stevens and Monsen 2004).

Seed drills concentrate seed into rows (Figure 10.92), creating a greater potential for competition between emerging seeds within rows than if seeds were broadcast. For example, a seed mix with an aggressive species will emerge and dominate the row of seeds at the expensive of less aggressive species. The three seedboxes on the Truax® seed drill can be used to compensate for this potential problem. The less aggressive species are placed in separate seedboxes and sown in separate rows. If more than one seedbox is used, separate sowing rates must be calculated for each box. Typically, lower seed rates are used in drilling operations because the seeds are concentrated in rows and closer together. Where rodents are present, drilled seeds are more prone to being excavated by rodents that simply follow a row of seeds (Stevens and Monsen 2004).

Seeds Covered With Long-Fibered Mulch – Optimum seed germination is obtained under long-fibered mulch. The mulch provides a moisture barrier that protects seeds and keeps soil from drying (Figure 10.93). Soil moisture is maintained longer around seeds than if they were strictly covered by soil. This is a two-stage operation in which seeds are broadcast on the soil surface and then covered by mulch. The thickness at which the mulch is applied depends on the seed size and the type of mulch. Small seeds will require less cover than large seeds. The rate at which mulch can be applied varies by the characteristics of each type of mulch. Wood strands and straw, for instance, can be applied at higher rates (thicker layers) than composts or chips because more light is able to penetrate these mulches, allowing seed germination and seedling establishment. See Section 10.1.3 for further discussion of mulches.

Sowing seed mixes that contain a variety of seed sizes will require that the mulch not be uniformly applied. One strategy is to begin with a roughened seedbed as shown in Figure 10.86. Because the surface is not even, mulch will settle in depressions and be thicker than on the ridges. Monitoring the application rates is important to assure that seeds are covered with the proper mulch thickness. While covering seeds with long-fibered mulch is the most favorable method for optimum seed germination, it is also the most expensive.

Figure 10.92 – Seed drills place seeds in rows under the surface where they are in direct contact with the soil.

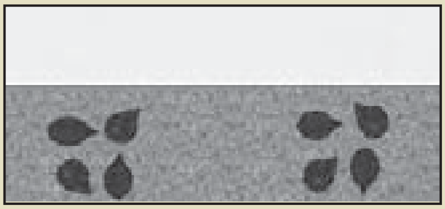
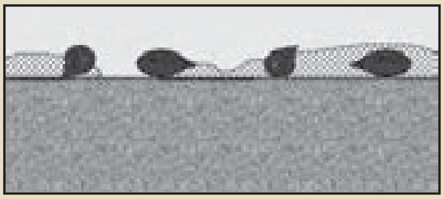


Figure 10.93 – Covering broadcast seeds with long-fibered mulch is very effective in conserving moisture around the seeds.

__Figure 10.94 –__ Seeds mixed into long-fibered mulch have less contact with soil, which can reduce germination.

__Figure 10.95 –__ Applying seeds in a hydromulch places a portion of seeds on the soil surface and some suspended in the hydroseeding matrix above the surface.



Seeds Mixed into Long-Fibered Mulch – Seeding and mulching are often combined into one operation (Figure 10.94). Most mulch blowers have seed metering systems which distribute seeds with the mulch as it is being applied to the soil surface. Seeds in this operation are distributed within the mulch, as opposed to being placed between the soil surface and mulch layer. Although one operation is more efficient, seed germination and seedling emergence rates are typically lower than when seeds are broadcast on the surface and covered with mulch. Seeds are not in contact with the soil when mulch and seed are mixed. Unless the mulch has a high water-holding capacity, moisture around the seeds will be limiting during germination and seedling emergence. It is important to know how much moisture a mulch can hold when deciding whether seeds will be mixed with the mulch or broadcast applied first then covered with mulch (See Section 5.2.2.1 for determining moisture holding capacities of mulches). Composts, for instance, have high water-holding capacities, and seeds will germinate well in this material; ground or shredded wood mulch and wood strands have very little water-holding capacity and seed germination will be poor. Seed rates should increase relative to how much moisture the mulch is expected to hold. For low water-holding capacity mulches, seeds in the upper portions of the mulch will not germinate or will germinate poorly. Seed rates in this type of mulch should be increased by 25% to 50%.

Seeds Applied in Hydromulch – When seeds are applied through a hydroseeder (See Section 10.3.2), they will lay on the soil surface surrounded by a thin covering of fine-textured wood fibers (Figure 10.95). At rates of 1,000 lb/ac hydromulch, seeds will be covered with less than 0.25 inch of mulch, with some seeds not covered. As rates approach 3,000 lb/ac, mulch thickness increases to over 0.25 inch, with most seeds being covered. Hydromulch has a high water-holding capacity, maintaining up to two and a half times its dry weight in water. This can be beneficial to seeds during germination. However, unless very high rates of hydromulch are applied, many seeds in the slurry are not covered by the hydromulch. Some hydroseeding operations try to compensate for this by applying a slurry containing seeds first, and covering the seeds with hydromulch with a second pass. The thin seed cover is favorable for only small seeded species. Seeds can be damaged in the hydroseeding operations through the pumps and agitators, or by hitting the ground at very high speeds during application.

Even with these limitations, hydroseeding is still one of the most common methods of applying seeds to road construction disturbances. It is often the only way to place seeds on steep, rough terrain encountered in mountainous regions. Compensation for these limitations has had varying degrees of success. Possible variations include: 1) increasing the amount of seeds, 2) applying seeds in the first pass, then covering with hydromulch in the second pass, and 3) applying higher rates of mulch. Fall hydroseeding also increases establishment rates. Over-wintered seeds are ready to germinate on the first warm days of late winter or early spring when humidity levels are high. In addition, hydraulic mulches are more likely to stay moist for longer periods of time. Hydroseeding is simpler than dry seeding because there is no seed metering system; seed mixes are simply mixed into the hydroseeder tank and applied. See Section 10.3.2 for more discussion on hydroseeding.

10.3.1.4 Formulate Seed Mixes

The seed mix refers to the species composition being applied over a seeding area. It is important to avoid applying a single species to a site. Since highly disturbed sites typically are extremely variable in soil temperatures, fertility, soil moisture, solar radiation, and other site factors, it is important to apply a number of species in a seed mix to assure that all possible microsites are populated (Monsen and Stevens 2004). Microsites that are unfavorable to one species might be favorable to others. Applying a mix of species also assures that if there is a problem with the germination of one species, the other species will fill in. The composition of seed mixes and sowing rates should be based on the growth habits of each species and the soils and climate of the site.

It is preferable to avoid mixing slow-growing species with fast growers, because the fast growers will out-compete the slow growers for space and resources (Monsen and Stevens 2004). Separating slow growers from fast growers is not always possible. The seed quantities must therefore reflect higher ratios of slow growers to fast growers to achieve some degree of success. Shrubs and trees are typically less aggressive than grasses during the establishment phase, and should be applied in a separate mix or planted as seedlings. Grasses tend to be more aggressive than forbs. However, if the Truax® seed drill is used, they could be applied in the same area but in different rows using the separate seed boxes. Some species take several years to develop. A mixture of fast-growing annuals and slow-growing perennials will assure that there is cover the first year, yielding to more robust perennials in the succeeding years.

Disturbed reference sites can be good indicators of species that are adapted to the climate and soils of the project area. Vegetative surveys conducted during the planning stages should show the proportions of species that can be expected, and these findings should become the basis for developing species composition and ratios of each species. Prior to determining sowing rates, the proportion of each species within each seed mix should be set. This information will be used to determine seeding rates for each species.

10.3.1.5 Determine Sowing Rates

The sowing rate is the amount of seeds of each species in a seed mix that are applied in a given area. Sowing rates are calculated for each species that compose a seed mix. These calculations are performed twice – once during the development of seed increase contracts to obtain an approximate quantity of seeds to propagate for the entire project, and several months prior to actual seeding when seed inventories are known and exact seeding areas are

Figure 10.96 – *Assembling a seed mix requires sowing calculations for each species in the mix. This figure shows one way to calculate the quantity of seeds for one species (e.g.* Elymus glaucus *[ELGL]) in a mix. These calculations must be made for each of the remaining species in the mix.*

A	Number of seeds/lb:	128,000	seeds/lb	From seed tests
B	Purity:	92	%	From seed tests
C	Germination:	89	%	From seed tests
D	A * B / 100 * C / 100 =	104,806	PLS/lb	Number of PLS per pound of bulk seed
E	First year survival:	20	%	The estimate of PLS of ELGL that become seedlings
F	Target 1st year seedling density:	20	seedlings/ft^2	Desired number of seedlings (per ft^2) of all species in seed mix after 1 year
G	Target composition:	35	%	Target percent of total 1st year plants composed of ELGL
H	(F / E) * G =	35	PLS/ft^2	PLS of ELGL to sow per ft^2
I	43,560 * H / D =	14.5	pounds/acre	Pounds of ELGL to sow on a per acre basis
J	Area to seed:	5.5	acres	Total area for seed mix
K	I * J =	80	lbs	Total ELGL needed for seed mix
L	Quantity of containers:	4	bags/acre	For handling
M	I / L =	3.6	pounds/bag	Total weight ELGL to put into each seed mix bag

located. The calculations made prior to seeding will be used to assemble the seed mixes for each seeding area.

Each species requires a set of data to calculate the total pounds of seeds needed in a seed mix which includes:

- Pure live seeds per pound of bulk seeds,
- Estimated first year survival,
- Target first year seedling density for all seeded species,
- Percentage of density composed of each species, and
- Area that will be seeded with seed mix.

Figure 10.96 shows one method for calculating the amount of seeds needed of each species in a seed mix. Since a seed mix is made up of several species, calculations must be performed on each species. In this example, blue wildrye (*Elymus glaucus*) is one of several species included in a seed mix. The end result of these calculations is the number of pounds of blue wild rye seeds that must be added to each seed mix bag.

Pure Live Seeds Per Pound (PLS/lb) – When purity and germination are multiplied together and divided by 100, the resulting value is the % pure live seeds (PLS). It represents the percentage of the gross seed weight that is composed of viable seeds (See Figure 10.65 in Section 10.2.4). For example, if germination is 89% and purity is 92%, the PLS would be 82%. When PLS is multiplied by the number of seeds per pound, the result is the pure live seeds per pound of gross seeds (PLS/lb). This value is often used in seed and sowing calculations, and it states the approximate number of seeds that will germinate in a pound of gross seeds under ideal (test) environments. For example, the PLS in Figure 10.96 is 82%, and the number of seeds per pound is 128,000. The total PLS/lb is (82/100) * 128,000 = 104,806 (Line D in 10.96). Tests for purity, germination, and seeds per pound are run by State Certified Seed Testing Laboratories and obtained from the seed producer or supplier.

First Year Survival – Not all viable seeds develop into established seedlings after being sown on a disturbed site. The conditions encountered on revegetation sites are generally unfavorable for germination and plant establishment. The first year survival factor reflects the effect of the harshness of the site on plant establishment (Line E of Figure 10.96). It is a prediction of the percentage of PLS that germinate and become established plants after the first growing season. A favorable site, for instance, will have a high survival factor because a high percentage of live seeds will germinate and establish into plants; a harsh site will have a low first year survival factor because seeds will germinate poorly, resulting in plants less likely to survive over the dry summer months. Unfortunately, there are currently no established field survival factors for the western United States. Therefore, the revegetation specialist will have to make estimates based on experience and an understanding of site factors, seed handling, and sowing methods.

How much fall down actually occurs? Even under very controlled growing environments, such as those found in seedling nurseries, survival factors are much lower than most would think. It is not uncommon for bareroot seedling nurseries to set first year survival values between 65% and 75% (USFS 1991). Compare the highly controlled environment of a nursery to seeding in the wild, where precipitation is intermittent and soils are depauperate. It should be no surprise to find that only 10% to 20% of the live seeds sown in the wild actually turn into live plants the first year after seeding (Monsen and Stevens 2004; Steinfeld 2005).

Estimating the first year survival is always a guess. It is interesting that very exact data from seed tests are used for a portion of the sowing calculations, followed by a broad approximation of how well viable seeds will actually germinate and become established in the field. Unfortunately, this information is hard to obtain. Monitoring data collected in the spring and fall, after the completion of each seeding project, can be used to develop a basic understanding of how seeds perform in the field under various soils, climates, and mitigating treatments. First-year monitoring that measures seedling density is useful in this regard. The number of seedlings can be counted in a series of photoplots, and the average number of seedlings per square foot can be calculated. The average seedling density, divided by the average number of PLS sown per square foot (line H of Figure 10.96), gives the survival factor for that project area. Steinfeld (2005) performed this type of monitoring for several seeding projects six months after sowing on southwest Oregon sites and found the results to be very low (15% of viable seeds became established plants). If this type of assessment is conducted over a range of seeding projects,

Table 10.16 – First year seedling survival is dependent on the quality of the germination environment. This table is a guide to setting first-year survival rates based on factors that influence germination. High first-year survival rates might be closer to 20%: low survival is often less than 5%.

	Estimated Field Survival	
	Low	**High**
Seed cover	none	mulch
Spring rainfall	low	high
Humidity	low	high
Water-holding capacity	low	high
Sowing method	poor	good
Season sown	fall	spring
Seed treatments	poor	good
Freeze thaw	high	low
Surface erosion	high	low
Aspect	south	north
Fertility	low	high

survival factors could be developed for a range of soil and climate conditions. It would be good to understand how survival factors change with different types of seed covering methods.

Factors to consider when estimating survival factors are shown in Table 10.16. Chapter 5 discussed how these factors affect plant growth. Sites with low first year survival would have a large number of limiting factors. Very poor sites can have survival factors below 5%, whereas favorable sites can have factors as high as 20%.

Target First Year Seedling Density **–** The target first year density is the number of plants/ft^2 desired the first year after sowing (Line F of Figure 10.96). Establishing target density factors is often based on the objectives of the project. For example, projects where the objective is fast plant establishment for either erosion control or weed prevention would usually require the target first year densities to be relatively high. Target densities are also based on the growth habits of the species to be sown. Fast-growing species with large spreading growth habits would have low target densities. Shrubs and trees would have target first year densities of less than 1 plant/ft^2, whereas grasses might have densities up to 25 seedlings/ft^2. Monitoring sites after one year can give a good indication of what densities can be expected from each species and what densities are most appropriate for meeting project objectives.

It should be recognized that there is a point of diminishing returns, where applying more seeds does not necessarily produce more seedlings. There is a limit to how many seedlings can survive on a site, and no amount of seeds applied will change this fact. While applying excess seed errs on the conservative side, it can be wasteful and costly. It can also favor the aggressive species over the less aggressive species (Monsen and Stevens 2004). When using high seeding rates, it is important to reduce the ratio of aggressive species to non-aggressive species in order to assure that non-aggressive species can become established.

Target Composition **–** The target composition is the proportion of each species that will comprise the seedlings found in a given area (Line G of Figure 10.96). An example of a target seed mix composition is one that would produce a stand of grass and forb seedlings made up of 35% blue wildrye (*Elymus glaucus*), 35% California fescue (*Festuca californica*), and 30% common yarrow (*Achillea millefolium*). See Section 10.3.1.4 for further discussion.

Area to Seed **–** The area to seed is the total acreage of a seeding area to which a seed mix will be applied (See Section 10.3.1.2 for a discussion on how seeding areas are determined.)

10.3.1.6 Prepare Seed Mixes

Once sowing calculations are completed for each species, seed mixing operations can begin. The objective of these operations is put together seed mixes in packages that are organized, easy to handle, and ready to use. This is an important step, because there can be no room for confusion in seeding operations or time for reorganizing seed mixes. The seed mixing operation involves weighing seeds from each species or seedlot, mixing seedlots, placing seeds in bags, and labeling.

The seed bag is the basic handling unit used in seeding. Before mixing begins, you must determine how much area a bag of seed mix will cover. This will depend on the seeding method. For hydroseeding contracts, the seed bags can be no larger than the area a slurry unit will cover (See Section 10.3.2). For example, if a 1,000 gallon hydroseeder tank covers a quarter acre, then the bags of seed mix would have enough seeds to cover a quarter acre. In this example, the seed mix is divided into four bags per acre (Line L of Figure 10.96). The most typical seed bag coverage is a quarter of an acre because of the increased flexibility, reduced weight, and ease of handling.

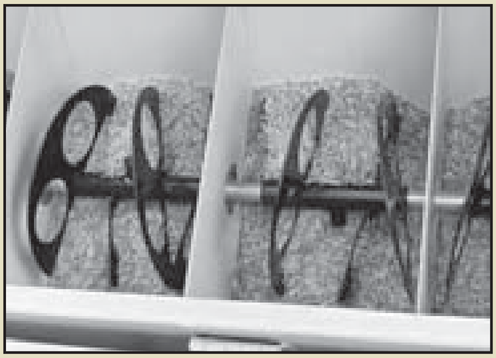
The sowing method is an important factor in assembling the seed mix. If the mix is to be used in a seed metering system (Inset 10.19), each seedlot must be thoroughly mixed together to ensure a uniform distribution of seeds of each species on the site. On the other hand, if the seed mix is placed in a hydroseeder, it is not necessary to mix the seeds since all seeds will eventually be mixed in the hydroseeder before application. Other packaging will be required if more than one seedbox is used (e.g., the Truax® seed drill).

Inset 10.19 – Seed Metering and Delivery Systems

The seed metering system is key to uniform application of dry seed mixes. Seed boxes should contain a mechanical seed agitator (as shown in picture) that constantly mixes the seeds to prevent seed bridging. The rate of seed flow must also be easy to adjust to allow for changes in sowing rates. Some systems, such as those found on mulch blowers, have remote controls that allow the applicator to turn the metering system on and off.

There are several types of seed delivery systems available, and the choice of the system will depend on project objectives. Some systems have more than one seed box to keep several species separate. This might be necessary when working with seed mixes that include chaffy or fluffy seeds. Specialized seed boxes that are manufactured with a semicircular seedbox, auger agitator, and pickerwheel, as developed by the Texas Agricultural Experiment Station (USDA/USDI 2005), can be used for these types of seeds.

Drilling different sized seeds may also require two or more seed boxes. The Truax® seed drill has three seedboxes that are adjusted to sow various seed sizes and shapes.



Other materials can also be included in the assembly of the seed mix. Mycorrhizal inoculum can be mixed with the seeds, as well as dyes to make seeds easier to see after seeding. Mycorrhizal inoculum and dye will change the rates that seeds will flow. Seed metering systems will have to be calibrated for these materials. Very small-seeded species may need to be sown with carriers, such as rice hulls (Stevens and Munson 2004). For small, fluffy seeds, wheat bran can be added to help prevent them from migrating upward in the seed mix (Dixon and Carr 2001b).

When calibrating seeds for mulch blowing operations, it will be necessary to create more small seed bags that represent smaller calibration areas (Inset 10.20).

10.3.1.7 Determine Seeding Date

The best date to sow varies by site, but typically it is in the fall. On cool, arid sites, seeding later in the fall is better to prevent premature germination prior to the onset of the winter (Monsen and Stevens 2004). On warm, moist sites (e.g., the west side of the Cascade Mountains), sowing can take place in the late summer and early fall, anticipating that seeds will germinate with early fall rains and become established prior to winter. If seeds are sown in the spring or early

Inset 10.20 – Calibrating Seed Densities for Mulch Blowing

Calibrating seed metering systems on mulch blowers to obtain the target seed density can be accomplished by laying out several plots of identical area (e.g., 1,000 square feet) with flagging. The seed required for each plot is determined and measured:

seed weight = plot area (sq ft) * (target pounds of seed mix/acre) / 43,560.

For example if the seed mix application rate is calculated at 30 lb/ac and the plot size is 1,000 ft^2, the weight of seed to apply per plot is 1,000*30/43,560, or 0.69 lb. Make at least 6 seed calibration bags. Prior to applying mulch, place the seeds from the calibration bag into the seed metering bin. Apply the mulch to the plot at the target depth while one person monitors the seeds being metered out. When all seeds are dispensed, stop the application and estimate the area covered by mulch. If the mulched area was approximately half of the 1,000 ft^2 plot (500 ft^2), the seed densities would have been doubled. Adjustments to the seed metering controls would need to be made to deliver 50% of the seeds. After these changes are made, mulch would be applied to another plot to determine if seeding rates were closer to the target rates.

summer, seed mixes should be composed of species that germinate quickly and do not require a long natural stratification period.

10.3.1.8 Assure Quality

There are several factors to monitor during seeding to assure operations are administered correctly. Depth of seed placement, uniformity in application, target seed densities, and seed handling must be monitored throughout the process. It is important to periodically measure seed depths, especially at the beginning of the operation or when any new site being seeded. Seed dyes are sometimes applied to make seeds more visible. However, these are not useful when seeds are applied through hydraulic seeders or mulch blowers. Uniformity of seed application can be monitored as seeds are being distributed through seed metering or delivery systems. Sometimes seed systems plug or malfunction, resulting in sporadic application of seeds. Poorly applied seeds, where the applicator either misses spots or applies over seeded areas, will also results in an uneven application.

Seed densities can be monitored indirectly by measuring the area where a known weight of seed has been applied and matching it to the estimated acreage it was targeted to cover. For example, on a project where a seed mix is split into a quarter-acre bags, the area seeded with one bag of seed mix would be measured. If a quarter-acre bag covered only 0.2 acres, the seed was sown more thickly and the density was increased by 25% (0.5/0.2). If the seed bag had been applied over 0.30 acre, the seeds would have been spread across more area and the seed density would have decreased by 17% (0.5/0.3). These measurements should be done as each seed mix is being applied. If there is a significant change in density, adjustments to the seeding operations can be made.

Measuring a seeding area unit is important not only for determining if seeding rates are being applied correctly, but also for accurately paying the seeding contractors. Contract administrators should be measuring the area that each seed bag or known seed quantity is being sown during, or immediately after, seed application. Figure 9.2 in Chapter 9 describes a method to measure area by measuring the slope length that has been seeded at each road station marker and multiplying it by the distance between markers.

Proper seed handling should also be monitored. Seed bags should stored in suitable conditions and always handled with care. Seed bags should not be thrown or dropped or left in unsuitable conditions.

10.3.2 HYDROSEEDING

10.3.2.1 Introduction

Hydroseeding is a method of hydraulically applying seeds, stabilizers, and soil amendments to the surface of the soil for the primary objective of revegetation. The term hydromulching is often used interchangeably with hydroseeding, but there is an important distinction; hydromulching is the application of hydraulic mulch and surface stabilizers for the primary purpose of erosion control. Hydromulching is typically conducted on multi-year construction projects, when surface soils need to be temporarily stabilized for soil erosion or dust abatement. While hydromulching and hydroseeding operations both must stabilize the soil surface, hydroseeding has the additional and overriding goal of placing viable seeds in a surface environment to germinate and grow into healthy plants. Meeting the dual objectives of erosion control and plant establishment in one operation is often a balancing act. The best methods for soil stabilization are not always optimal for seed germination and plant growth. In this section, we will focus on hydroseeding, not hydromulching. We will discuss how to best meet the needs of early plant establishment using hydraulic sowing methods and leave the discussion of stabilizing the surface through hydromulching to the many articles on this subject and to the manufacturers of these products.

Hydroseeding equipment is composed of: 1) a tank that holds a slurry of water, seeds, soil amendments, and stabilizing products; 2) paddles or agitation jets in the tank to mix the slurry; 3) a high pressure pumping system; and 4) a hose and nozzle (Figure 10.97).

Tanks come in a variety of sizes, from a few hundred to over 3,000 gallons. As the size of the tank increases, the speed and efficiency of the operation improves. Because the travel time is the same for any size hydroseeding unit, the farther the water source is from the project site, the more efficient larger tanks become.

The hydroseeding tank is analogous to a large mixing bowl filled with various ingredients and blended together with water to make a slurry. Typical hydroseeding ingredients fall into these categories:

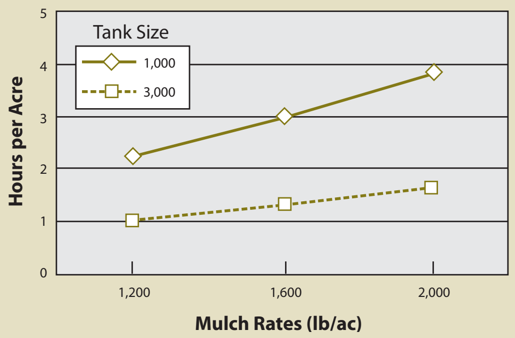
- Seed,
- Hydraulic mulch,
- Tackifier,
- Fertilizer,
- Soil amendments, and
- Dye (typically in the hydraulic mulch).

The mixture of ingredients is called a slurry. When a slurry is applied to an acre, it is referred to as a slurry unit. The quantity of each material added to a slurry tank is only limited by the ability of the mixture to be pumped through a hose and shot through a small nozzle without clogging. The tank can only hold so much material before the mixture becomes too thick to pump. Finding the right mix and rates of ingredients is important for efficient use of the equipment. The applicators and manufacturers of these products can recommend optimum product rates.

Hydroseeding ingredients must be thoroughly blended prior to application to achieve uniform seed coverage. There are two types of hydroseeding mixing systems – those that mechanically stir and those that mix using a hydraulic jet. The first system employs rotating paddles to blend the slurry in the tank and a centrifugal pump or positive displacement gear pump for slurry delivery. The second system uses a centrifugal pump to both agitate the slurry and deliver the slurry to the site.

***Figure 10.97** – The hydraulic seeder is composed of a tank that holds and mixes a slurry, and a pump system that moves the slurry through a nozzle for application to the soil surface.*

Figure 10.98 – Hydromulch application time can be roughly calculated from the size of the mixing tank and the application rate. Cycle time (the time it takes to drive from the water source to the spray area, discharge the slurry, and return) used in this analysis was 60 minutes for a 3,000 gallon tank and 45 minutes for a 1,000 gallon tank (figure modified after Trotti 2000).



During application, the slurry is pumped to the nozzle for application. The applicator has a choice of nozzles, use of which depends on the site and slurry conditions. Slurry application can be from a "gun" mounted on the top of the hydroseeding unit or from a hose pulled manually to the application site. Stationary application (using a hydroseeding gun) is accomplished where the hydroseeding equipment can easily access the site. These areas are typically cut slopes and fill slopes. Depending on the consistence of the slurry, the pumping system, and wind conditions, slurry can be shot 200 feet or more. Hoses are laid out for sites that cannot be reached this way. Depending on the diameter of the hose and the pumping system, hoses can reach sites over 300 feet from the hydroseeding unit.

Hydroseeding is used when other seeding methods are impractical (See Section 10.3.1, Seeding). Typically, these are steeper sites where ground based seeders are limited. Hydroseeding has the advantage over other seeding methods of applying soil amendments, fertilizers, soil stabilizers, and seeds together in one operation, making this a one pass operation. In addition, seeds that are used in hydroseeding operations do not have to be as clean (that is, free of straw, awns, chaff) as for other seeding methods. This can reduce costs and time associated with seed cleaning operations.

The time it takes to hydroseed is a function of the size of the mixing tank and the amount of hydraulic mulch that is applied on a per acre basis (Figure 10.98). The greater the amount of hydraulic mulch applied per acre, the longer it will take. For example, it takes almost twice as long to apply 2,000 lb/ac of hydraulic mulch through hydroseeding equipment as it does to apply 1,200 lb/ac. For this reason, determining the appropriate amount of hydraulic mulch is important from a cost standpoint. Cost includes not only the costs of purchasing the product, but also the time to apply it. Tank size is also an important factor in application rates; the larger the tank size, the less application time it takes. A 3,000 gallon mixing tank for example, takes less than half the time to cover an acre than a 1,000 gallon tank.

Hydroseeding in wildland revegetation has a number of limitations (Stevens and Monsen 2004):

1) Seeds are not placed in the soil
2) Seeds and seedlings can dry out
3) Some seedlings cannot grow through the hydraulic mulch
4) Seeds can be damaged by agitators and pumps
5) Precocious germination can occur as a result of moisture in the hydraulic mulch
6) Hydroseeding requires large quantities of water

With good planning, implementation, and monitoring, many of these limitations can be managed, resulting in successful revegetation. Ultimately, the success of any hydroseeding project comes down to the availability of water during germination and seedling establishment. Hydroseeding is successful in the landscaping business because seeds are irrigated after hydroseeding until a stand of grass has become established. As one applicator stated, "what people don't understand is you can do the best hydroseeding job in the world but if they don't water it, it's not going to grow" (Brzozowski 2004). The challenge in wildland revegetation is that, for most projects, irrigation is not available. To make hydroseeding successful, strategies must be developed that maintain moisture around the seeds and in the soil during early plant establishment.

10.3.2.2 Integrate Hydroseeding into Revegetation Strategy

From a revegetation standpoint, hydroseeding serves as: 1) a method of seed placement, 2) a means of stabilizing the soil surface for controlling erosion and to allow seedlings to become established, and 3) a way to apply fertilizers and other soil amendments. These objectives cannot always be met in one hydroseeding operation. It often requires that each objective be considered independently, and then integrated into an overall strategy. Clarifying objectives, based on the site specific conditions of the project, and determining the best way to achieve them using hydroseeding equipment as part of the approach, will lead to the best revegetation results. For example, seed placement and fertilizing are different objectives, yet meeting both objectives is often accomplished in one hydroseeding operation out of convenience. However, the best time to apply fertilizers on many projects is after the seeds have germinated (See Section 10.1.1). Instead of meeting fertilizer and seeding objectives in one hydroseeding operation, separating them into two different applications would be a better strategy for meeting overall project objectives.

On a site with high surface rock, for example, the main objective would be seed placement. Little importance would be placed on surface stabilization since the rock has already created a stable surface. The best potential sites for seedling germination on this harsh surface would be between the surface coarse fragments, where seeds are protected and moisture collects. Yet a common mistake that occurs in many hydroseeding projects is to include the same rates of tackifiers as would be used on a soil surface. Under these circumstances, tackifiers adhere seeds to the rock surface, preventing the seeds from washing between the gravel and cobbles that cover the surface. The objective of stabilizing the surface is not only unnecessary in this example, it would negatively affect placement of seeds.

Hydroseeding should always be accomplished within a strategy of creating an optimum seed environment. The hydroseeding operation places seeds on the surface of the soil which is often a poor environment for germination. Hydraulic mulch is inferior to long-fiber mulches in reducing surface temperatures, maintaining soil moisture, and moderating surface temperatures (See Section 10.1.3). The term "hydraulic mulch" is misleading because most materials that fall into this category lack many of the important properties associated with mulches (See Section 10.3.2.5). By their nature, hydraulic mulches are more like a growing medium than mulches because of their capacity to absorb water (Most hydraulic mulches hold greater than 1,000 times their weight in water).As a growing medium, hydraulic mulch maintains high moisture around the germinating seeds. But once the hydraulic mulch dries out, which is often very quickly on dry sites, it no longer protects the seeds from drying as a mulch would and germination rates are compromised.

The literature is scant and inconclusive on the benefits of hydraulic mulch to seed germination and seedling establishment in wildland conditions. Carr and Ballard (1980) found no difference in plant establishment when seeds were applied with and without hydraulic mulches, but only low rates of hydromulches were compared. One approach to increasing seed germination that is often used in drying climates is a two pass application system, where seeds and a minimum amount of hydraulic mulch are applied in the first pass, then covered by a thick application of hydraulic mulch in a second pass. While this application method appears to have some advantage over a one pass operation because the seeds are covered with a greater thickness of hydraulic mulch, it is not known what the difference in germination and seedling establishment rates might be. The benefits from a germination standpoint are probably not seen until the hydromulch rates are high (3,000 lb/ac or greater). Even then, on arid sites receiving less than 6 inches precipitation, higher hydraulic mulch rates can intercept the low amount of precipitation that is received, preventing moisture from reaching the seeds (See Section 5.2.2). Since it is uncertain whether hydraulic mulches improve germination, it is better to base mulch rates on surface stability objectives than on seeding objectives and use other methods to improve seed germination. For example, it might be more effective to reduce the amount of hydraulic mulch to the minimum amount necessary to apply seeds and, with the costs savings, apply a long-fibered mulch in a second operation.

10.3.2.3 Identify Hydroseeding Areas

Hydroseeding should take place after the final slope shaping and topsoil placement have been completed. Several months before hydroseeding is to take place, the site must be visited to finalize an implementation plan that includes the locations of where the plants or cuttings are to be installed and where seeding will take place. While most of the hydroseeding areas will conform to the revegetation units developed during planning, things always look different after construction. In this field review, the exact locations of the areas that will be hydroseeded are drawn on a road map and areas are identified where different seed mixes, fertilizer types/ rates, or hydraulic mulch rates will be applied.

The acreage for each hydroseeding area is calculated using methods described in Figure 9.2 in Chapter 9. This method partitions the cuts lopes and fill slopes into rectilinear units by road stations and calculates acreage between each unit. This information is then summarized in a hydroseeding table (shown in Figure 10.107) that is used to develop task orders. It can also be used in the field for keeping record of acreages and location of hydroseeding operations.

The proximity to streams must be considered when locating hydroseeding areas. If hydroseeding areas are adjacent to ditches or waterways that drain into live streams, a buffer should be included around these features to avoid entry of fertilizers into the stream system. Fertilizers applied to these sites have the potential of entering the ditches during rainstorms and eventually reach a stream course as nutrient pollution. Road runoff can be a significant contributor of nutrients to water systems (Reuter and others 1998).

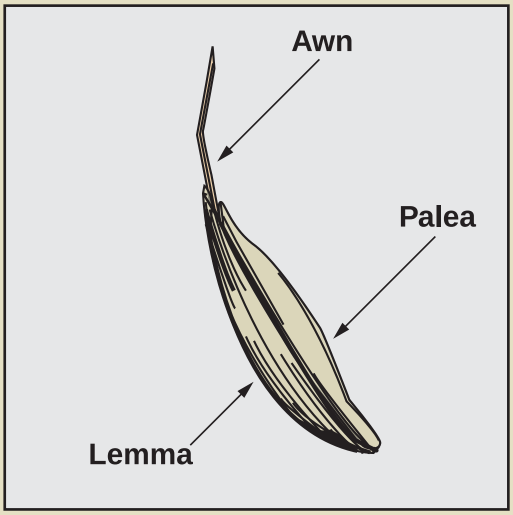
10.3.2.4 Determine Seeding Rates

Sowing rates for hydroseeding are calculated using the same method outlined in Figure 10.96 in Section 10.3.1. The reader is referred to this section for determining seeding rates for any type of sowing method. These sowing calculations assume that the method of sowing does not cause damage to seeds. This might not be a good assumption with hydroseeding, which has been shown to increase the risk of seed breakage in the hydraulic seeder tank during mixing (Kay and others 1977; Wolf and others 1984; Pill and Nesnow 1999). Additions of fertilizers further increase the risk by exposing seeds to high salt levels when seeds are in the slurry tank and also after they are applied to the soil surface (Brooks and Blaser 1964; Carr and Ballard 1979; Brown and others 1983). Taking precautions to reduce the risk of seed damage during hydroseeding will increase the seed germination rates and reduce the amount of seed needed for the project.

Considerations that can reduce the risk of damaging seeds include:

- Type of hydraulic seeder,
- Seed condition,
- Duration in slurry,
- Seed moisture,
- Hydraulic mulch,
- Nozzle and nozzle position, and
- Fertilizers.

***Figure 10.99** – Grass seeds are protected by sets of bracts called the lemma and the palea (the lemma is the larger, outer covering, and the palea is the shorter, interior sheath). The awn is a fibrous bristle that extends from the midrib of the lemma. The awns for most grass species are removed during cleaning for easy sowing. The lemma and palea should be kept on the seeds to protect them from seed damage during sowing, especially in hydroseeding operations.*



Hydraulic Seeders **–** Hydraulic seeders that use centrifugal pumps for agitation and delivery can have a higher potential to damage seeds than systems with paddles and rubber-coated gear pumps (Kay 1972a; Kay and others 1977). Kay (1972a) found that germination of intermediate wheatgrass (*Agropyron trichophorum* [Link Richt.]) seeds was reduced from 80% (control) to 10% germination after one hour in a centrifugal agitation system; after two hours, germination was reduced to 1%. There was no reduction in germination after one hour using paddle agitation, but germination declined to 59% after two hours. Pill and Nesnow (1999), however, found that centrifugal pumps did not reduce germination rates of Kentucky bluegrass (*Poa pratensis*) and perennial ryegrass (*Lolium perenne*) after mixing for an hour in a slurry tank.

Seed Condition **–** Grass seeds are enclosed by sets of bracts, called the lemma and palea. These structures provide a protective covering (Figure 10.99) and are believed to reduce seed breakage during hydroseeding agitation and application. In the aforementioned study, Pill and Nesnow (1999) believed that one of the primary reasons there was no decline in germination after an hour of mixing in a slurry tank was because the lemmas and paleas were still intact around the seeds. The association between presence of these seed structures and protection from seed breakage during hydroseeding should be considered when cleaning seeds for hydroseeding. Seed cleaning is necessary for storage and seeding (See Section 10.2.1 and Section 10.2.4). However, seeds for use in hydroseeding operations do not have to be as clean as seeds used in other seeding methods. Each species has different cleaning requirements for hydroseeding. Some require thorough cleaning, while others might require very little cleaning. It would be beneficial to discuss the level of seed cleaning for hydroseeding with your seed extractory personnel and seed increase contractors.

Duration in Slurry **–** The longer seeds are mixed in the slurry tank, the greater the potential for breakage. Kay and others (1977) found that after 20 minutes of agitation, seed germination decreased significantly (Figure 10.100). For this reason, it is important to add seeds immediately before application.

Seed Moisture **–** As a general rule, moistened seeds have less potential for breakage than dry seeds because they are more flexible when impacted. Kay and others (1977) found that soaking seeds for 1.5 days prior to application significantly increased germination over dry seeds (Figure 10.100). Longer soaking periods (4 days) had negative effects on germination because radicles were emerging and were damaged with mixing.

Soaking seeds prior to hydroseeding will unfortunately initiate seed germination, which is not usually desirable for hydroseeding projects. Pill and Nesnow (1999) suggest seed priming as an alternative to soaking. Priming is a seed treatment that partially moistens seeds without initiating seed germination (Pill and others 1997). Seed is mixed at one part seed to 10 parts moist vermiculite (although peat could be used as a substitute) and stored at cool temperatures for up to 10 days prior to hydroseeding.

Hydraulic Mulch **–** Hydroseeding without hydraulic mulch can increase seed damage (Kay 1972a, 1978). Using a minimum rate of 500 lb/ac hydraulic mulch is suggested for protecting seeds (Kay 1978).

Figure 10.100 **–** *Using a centrifugal hydroseeding pump system, Kay and others (1977) found a reduction in germination of Bermudagrass (Cynodon dactylon) seeds after 20 minutes in the slurry tank. Seed germination improved when the seeds were soaked in water for 1.5 days prior to placing in a hydraulic seeder tank. However, soaking for longer than 1.5 days reduced germination more than if the seeds were not soaked (modified from Kay and others 1977).*

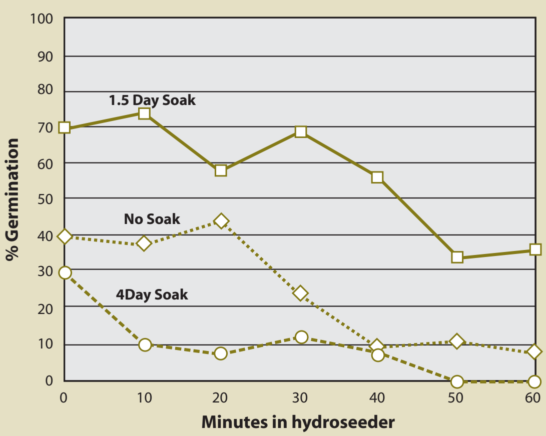
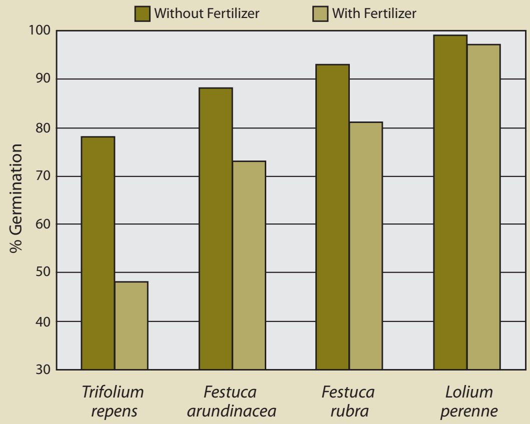


Figure 10.101 – Incorporating 10-30-10 fertilizer into hydroseed slurries can reduce the germination of some species (Carr and Ballard 1979).



Nozzle Type and Nozzle Position **–** Shooting slurry straight at the soil in close range can damage seeds. The impact at high speeds can cause seed coats to break. As one hydroseeding operator describes the action, "we just shove that seed right smack in the ground with a lot of force...the gun was slamming straight to it" (Brzozowski 2003). Describing this action to a Forest Service seed extractory specialist, his reaction was, "that can't be good for the seed" (Barnar 2007). In the seed production and seed extraction businesses, handling seeds carefully is a high priority. This attitude and practice should not stop with the seed producers, but follow through to the application of seeds. One application practice that could reduce seed damage is to aim nozzles so the slurry is not hitting the soil surface with full force at close range. Arching the slurry stream so the spray hits with lower force is more desirable. Using less pressure or lower pressure nozzles, such as fan nozzles, can also reduce seed damage (Figure 10.102). Some soils are very loose or powdery after construction, which can cushion the seeds, as opposed to very compacted surfaces. Seeds applied to these surfaces can be buried under the loose soil when the slurry is shot straight at the surface, offsetting the effects of seed breakage and increasing germination potential (Mast 2007).

Fertilizers **–** Adding fertilizer to the slurry can reduce germination of certain species due to the effects of fertilizer salts on seed imbibition, or uptake of water (Brooks and Blaser 1964; Carr and Ballard 1979; Brown and others 1983). This is not just a problem when seeds and fertilizers are mixed together in the slurry tank; it can also negatively impact the seeds after they are applied to the soil surface and before the first rains dilute the surrounding salts. Effects of fertilizer salts will be more detrimental on sites with low rainfall. Carr and Ballard (1979) found white clover (*Trifolium repens*) and, to a lesser degree, *Festuca* spp. had the greatest reduction

Figure 10.102 – *Hydraulic seeders are equipped with several types of nozzles. The nozzle shown in photograph (A) shoots long, high pressure, streams while the fan nozzle shown in (B) spreads the slurry out for closer applications.*

in germination. They suggest white clover should be applied by hand, separate from the hydroseeding operation.

Assuming that most native seeds, especially legume species, are affected by fertilizer salts, it is important to understand what the effects of different types and rates of fertilizers will have on the salt concentrations in the slurry. Brooks and Blaser (1964), Carr and Ballard (1979) and Brown and others (1983) used inorganic, fast release fertilizers, which dissolve quickly in solution (See Section 10.1.1). Organic and control release fertilizers, on the other hand, dissolve slowly and therefore should have lower salt levels in solution. Whichever fertilizers or rates are used, testing the slurry for soluble salts should be conducted to assure that concentrations are not lethal (See Section 5.5.5).

The effect of hydroseeding operations on seed viability is an important issue and deserves more research attention. Monitoring information can be used to broaden our understanding on how to properly use this important tool.

10.3.2.5 Select Hydraulic Mulch and Determine Rates

Hydraulic mulch is a low bulk density material applied through a hydraulic seeder to increase surface soil strength and reduce erosion. At high application rates, seeds are covered, thereby increasing the potential for increased seed germination. Commercial hydraulic mulches are derived from wood fiber, recycled paper (wood cellulose), sterilized grass straw, or a combination of the three. Wood fiber mulches are manufactured from wood chips thermally treated by a steam and high pressure shredding process; wood cellulose mulches are made from waste paper materials such as recycled newspaper and cardboard (Trotti 2000). Hydraulic mulches typically have very high water-holding capacities (over a 1,000 times their weight in water). A pound of wood fiber mulch, for instance, absorbs between 1.5 to 2.5 gallons of water and, inversely, a gallon of water holds between 0.40 and 0.66 lb hydraulic mulch. This is important information to know when determining how much hydraulic mulch to add to a slurry tank. Most operators will not exceed a ratio of 0.4 to assure they do not clog their system with a slurry that is too thick. At this proportion, a 1,000 gallon tank would hold 400 pounds of wood fiber mulch. Product specification sheets should indicate the ratio of hydraulic mulch to water for hydroseeding equipment.

The depth and cover of hydraulic mulch depends primarily on the quantity and properties of the mulch placed in the tank. Typical hydroseeding projects range in application rates from 500 to 3,000 lb/ac. At low application rates (<1,000 lb/ac), wood fiber mulch will not cover the entire soil surface, leaving most seeds and much of the soil surface exposed. At high rates (>3,000 lb/ac) the soil surface and seeds are usually completely covered (Figure 10.103). With the appropriate mix of tackifiers, hydraulic mulch rates above 3,000 lb/ac can bond together

Figure 10.103 – *Hydraulic mulch applied at high rates and with specialized tackifiers will hold together as a sheet and is referred to as a "bonded fiber matrix," or BFM. The application rate of wood fiber mulch in this picture was 3,000 lb/ac.*

to form a continuous sheet, called a bonded fiber matrix, or BFM. A bonded fiber matrix will stabilize seeds and control surface erosion up to a year after application.

The length of the wood or cellulose fibers is an important characteristic in creating a soil cover mulch that does not restrict seed germination or plant growth. Cellulose mulches have shorter fibers than wood fiber mulches and, because of this, these materials compact much easier when they are applied. Applying too much cellulose mulch can result in a soil surface that has the consistency of "paper mache." At application rates greater than 1,500 lb/ac cellulose mulch, there is a reduction in infiltration and air exchange, and seed germination and seedling establishment are decreased (Gassman 2001). Some manufacturers have overcome this problem by mixing straw, a long-fibered material, with paper mulch. Typically, cellulose mulch requires 20% to 40% more material to achieve the same uniformity of coverage as wood fiber mulch (Trotti 2000) (Figure 10.104). While recycled paper mulches are typically less expensive than wood fiber, the cost savings are partially offset by the increased amount of paper mulch used. Blended mulches (those with equal portions of wood fiber with recycled paper) are an effort to improve the characteristics of recycled paper by adding wood fiber.

The use of hydraulic mulch for seed germination becomes less important on wetter sites, especially in climates where there is little soil drying during germination (Carr and Ballard 1980). These conditions are found from fall through early spring on many sites in the Coast Range and Cascade Mountains, and microsites that include north aspects and sites shaded by vegetation. On these sites, 1,000 lb/ac or less might be sufficient for seed germination. In areas with high rainfall and erosive soils, higher hydraulic mulch rates or even a bonded fiber matrix might be needed to keep seeds and soil in place until seeds have germinated and grown into established seedlings.

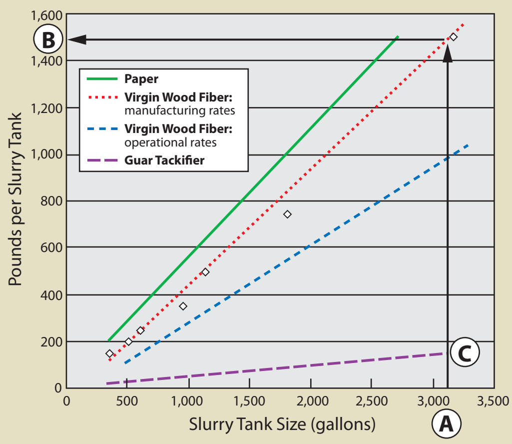
10.3.2.6 Select Tackifier

Tackifiers are sticking agents that bind soil particles together and protect the surface from wind and water erosion. When applied with hydraulic mulch, tackifiers increase the effectiveness of the mulch as a soil cover by binding the hydraulic mulch fibers and the surface soil particles together. Tackifiers create water-stable surfaces, which means they are capable of repeated wetting and drying and do not lose strength after a series of rainstorms. Hydraulic mulch and tackifiers can remain effective even through a winter with high precipitation (Figure 10.105).

Selecting a tackifier can be difficult. There are numerous commercially available products on the market from which to choose. Unless you have used these products side by side in the field, it is difficult to know the difference. A hydraulic seeder operator can offer advice on tackifiers and

***Figure 10.104** – The slurry tank can hold only so much material before the slurry becomes too thick to pump through the system. This graph gives a general relationship between the size of the slurry tank and the maximum amount of hydraulic mulch it can hold (modified from http://www.bowieindustries.com).*

Since virgin wood fiber mulch holds more moisture than paper mulch, less virgin wood fiber mulch can be added to a slurry tank. For a project utilizing a 3,200 gallon slurry tank (A), a maximum of 1,500 lb virgin wood fiber mulch (B) can be placed in the tank with 150 lb guar tackifier (C). Guar tackifier rates are based on a ratio of 1:10 guar to wood fiber mulch. At a prescribed rate of 1,000 lb/ac of wood fiber mulch, this slurry tank will cover approximately 1.5 ac. If the application rate is 3,000 lb/ac virgin wood fiber mulch, it will take 2 tanks.



other hydraulic seeding products, since they have tried a variety of products and would usually have a good idea of effectiveness.

There are two general types of tackifiers commonly used in hydroseeding – organic and synthetic. Organic tackifiers are derived from plant materials which include guar, plantago, and other plant starches. Synthetic tackifiers are manufactured polymers and copolymers that include polyacrylamides (referred to as PAM), acrylic polymers and copolymers, methacrylates and acrylates, and hydro-colloid polymers. Organic tackifiers break down biologically and are typically effective for at least three months, depending on site conditions and product type. Synthetic tackifiers are photo and chemically degradable and have somewhat greater longevity than organic tackifiers, lasting up to a year on many sites (CASQA 2003b).

Figure 10.105 – *Hydraulic mulch with tackifiers remain effective for up to a year. This hydraulic mulch and tackifier slurry was applied nine months prior to this picture, and was still partially effective.*

Revegetation specialists and operators usually develop a preference for tackifier products based on: 1) ease of handling and storage, 2) ease of application, 3) toxicity to plants, 4) environmental concerns, 5) weather restrictions, and 6) application rates.

Handling and Storage – Tackifiers are available as dry powder or liquid formulations. Most organic and some synthetic tackifiers are packaged as dry powders. These products are easy to handle and store because they weigh less and have less bulk than liquid containers. Liquid tackifiers must be stored in areas that will not freeze if stored over the winter. Handling and disposal of plastic containers is also a consideration when using liquid tackifiers.

Ease of Application – An important property of tackifiers is viscosity. Viscosity is the measure of the "stickiness" of a tackifier, or the propensity of the tackifier to hold a slurry together when it is applied. Tackifiers with high viscosity, such as guar based tackifiers, will hold the slurry together as a fine stream when pumped from the nozzle (Figure 10.106A), and the stream of slurry will shoot farther. When a slurry with high viscosity hits the soil surface, it sticks and does not easily run off. A slurry with low viscosity, on the other hand, will separate as it is comes out of the nozzle and drift, especially if there is a breeze, resulting in uneven application (Figure 10.106B). If low viscosity slurries are applied at rates that are greater than the soil infiltration rates, the slurry will run off the surface. Not only will seeds be lost, but other materials in the slurry (including fertilizers) have the possibility of moving into surface drainage systems (Figure 10.106C).

Tackifiers act as lubricants and create less friction through the hydraulic equipment. With high viscosity tackifiers, equipment runs smoother and nozzles do not plug as frequently. This will enhance the overall performance and longevity of the equipment.

Toxicity to Plants – One reason organic tackifiers are sometimes preferred over synthetic tackifiers is the belief that these materials are better for seed germination and seedling establishment. They are organic substances that break down into non-toxic compounds. While organic tackifiers are sometimes advertised as being better for plant health, there is nothing in the scientific literature to indicate that synthetic tackifiers are any more harmful or toxic to plant establishment than organic tackifiers.

Environmental Concerns – There have been concerns about the use of polyacrylamides (PAM) on human health and the environment. Acrylamide, a known neurotoxin to humans, is the main ingredient of this polymer. Polyacrylamides alone have low toxicity – LD50 of 5,000/kg oral dosage (Peterson 2002). However, in the manufacturing of the polymer, some acrylamide is formed. The US Food and Drug Administration has set a maximum allowable acrylamide content in PAM of 0.05%. While PAM does not appear to break down in the environment to acrylamide, if released during decomposition, it is thought to be quickly decomposed by soil microbes (Peterson 2002). Furthermore, since PAM degrades slowly in the environment, there should not be an accumulation of acrylamide in the soil (Claassen and Hogan 1998). Evans (2006) cites reviews by Barvenic (1994) on health hazards and Goodrich and others (1991) on aquatic macrofauna, edaphic microorganisms, or crop species. When polyacrylamides were applied at recommended rates, the materials were found to be safe for the environment. The reader is referred to Barvenik (1994) for a comprehensive discussion of PAM in the environment.

As with all products used in revegetation, a material safety data sheet should be requested from the manufacturer of the product and reviewed for possible human effects and effects to the environment. Some states have regulations on the use synthetic polymers in landscaping. It is important to be abreast of the latest environmental regulations (Peterson 2002).

Weather Conditions – Tackifiers have limitations and conditions for proper application, including: soils must be moistened prior to application; there must be a 1- to 3-day drying period after application; the site cannot freeze during or immediately after application; or they must be applied between a certain temperature range. It is important to understand which environmental restrictions apply to the tackifier you are using and how it might affect the hydroseeding operations. A site that is expected to be wet in the fall, for instance, will require a tackifier that needs a minimal curing period.

Tackifier Rates – When tackifiers are used with hydraulic mulches, tackifiers are applied at rates at 5% to 10% of the weight of the hydraulic mulch (CASQA 2003a). Refer to manufacturer labels for specific rates.

Figure 10.106 – *High viscosity tackifiers, mixed at manufacturer recommended rates, keep the slurry together during application using a "stream" nozzle (A). Low viscosity tackifiers, or slurries with low concentrations of tackifiers, do not hold together when applied and will drift with wind (B) or run off slopes (C).*

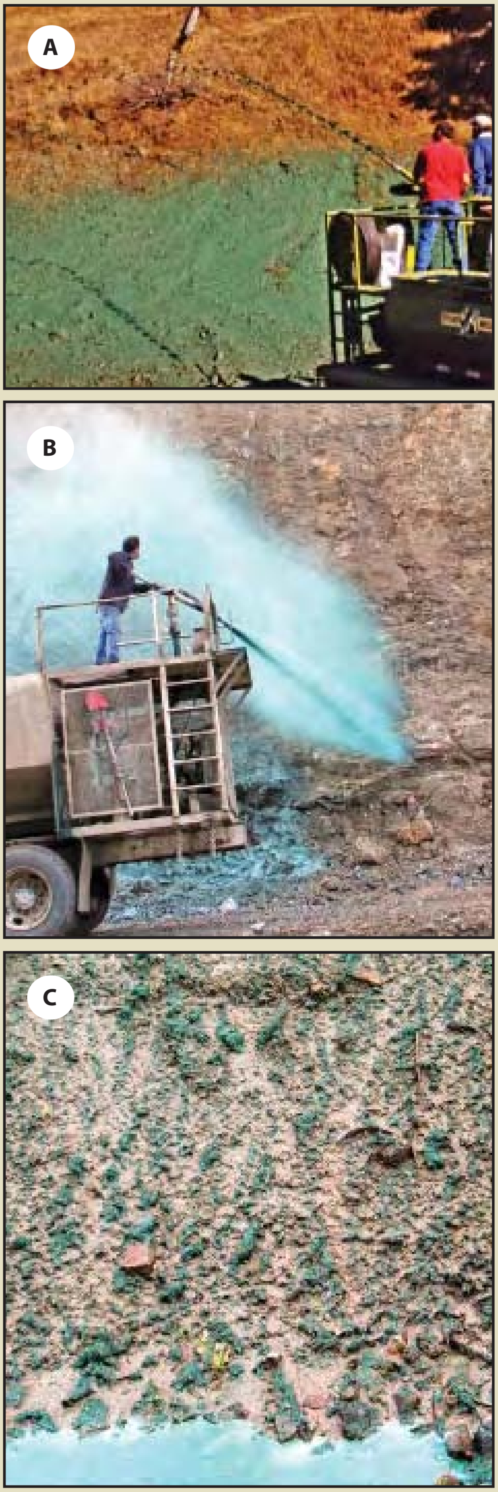


Figure 10.107 *– Prior to hydroseeding, review the areas to be hydroseeded in the field. For each road station (column C), the length of the slope (column D) that will be hydroseeded is measured (or estimated) and recorded. This information is placed in a spreadsheet as shown in this figure and acreage for each station is made by multiplying slope length by distance between stations (column E) and converting to area units (columns F and G) (e.g., acres). During hydroseeding, the stations and percentage of area to be covered (column B) within the station are recorded for each slurry tank (column A). Partial station coverage is estimated and acreages adjusted, as shown in the last entry in this example. When the slurry is completed, the total acres for that slurry tank are summed.*

A	B	C	D	E	F	G
Tank	% Covered	Station	Slope Length (m)	Distance between stations (m)	Area (m^2)	Acres
4	100	20+1000	27	20	540	0.133
4	100	20+1020	24	20	480	0.119
4	100	20+1040	25	20	500	0.124
4	100	20+1060	24	20	480	0.119
4	100	20+1080	25	20	500	0.124
4	100	20+1100	27	20	540	0.133
4	100	20+1120	26	20	520	0.128
4	50	20+1140	28	20	560	~~0.138~~ 0.069
		20+1160	23	20	460	0.114
		20+1180	21	20	420	0.104
		20+1200	26	20	520	0.128
		20+1220	22	20	440	0.109

Acres covered by Tank 4 = 0.95

10.3.2.7 Select Other Slurry Components

The remaining components of the hydroseeding slurry can include dyes, fertilizers, biostimulants, and mycorrhizae.

Dyes **–** Dyes are used as markers for the applicator to indicate where the slurry has been applied. Most hydraulic mulches include dyes, so it is not usually necessary to include dyes in the slurry when using these mulches.

Fertilizers **–** Fertilizers are often applied through hydroseeders. Determining the type and amount of fertilizers to use is discussed in Section 10.1.1.

Biostimulants **–** Biostimulants are sometimes applied to the slurry.

Mycorrhizae **–** Mycorrhizae are often included in the slurry (See Section 10.1.7, Beneficial Soil Microorganisms).

10.3.2.8 Locate Water Source

It should go without saying that you cannot hydroseed without a water source, yet a common mistake is to wait until the last minute to locate a source. For many parts of the western United States, water sources can be long distances from the project site. It is important to establish early where water will be obtained for hydroseeding early in the planning process.

Considerations when selecting a water source include:

Distance **–** On projects where the water source is a long distance from the hydroseeding site, large slurry tanks will increase the efficiency of the operation. Conservation of water should be a priority in these circumstances. Covering more area with each slurry tank is one way to reduce water needs. This can be accomplished by applying lower rates of hydraulic mulch and tackifier per acre.

***Water Quality* –** The quality of the water for hydroseeding must be low in salts and other potentially toxic compounds. If in doubt, send a sample to a water quality lab for testing or, at minimum, run pH and conductivity measurements on a sample.

***Water Use Permits* –** Always check with the agency or landowner for permits to use their water.

10.3.2.9 Develop Hydroseeding Contract

Once a basic hydroseeding plan is developed, a contract is developed. The contract usually contains most of the following elements:

***Site Location and Description* –** A general description of the site, slope gradients, location, and time of year the hydroseeding will occur should be addressed.

***Products and Rates* –** The hydroseeding products or equivalent products (hydraulic mulch, tackifiers, fertilizers, and so on) are identified, and the rates per acre for each product are stated for each hydroseeding mix or mixes. The total number of acres for each hydroseeding mix must be tabulated.

***Water Source* –** The location and distance to each water source are described. The contract should indicate whether it is the responsibility of the contractor to obtain agreements from owners for use or any required water permits.

***Storage Area* –** The contractor will want a site to store hydraulic mulches, tackifiers, fertilizers, and other materials associated with the hydroseeding operation. The site should be in close proximity to the hydroseeding areas and relatively safe from vandalism.

***Equipment* –** If specific types of hydraulic seeders are required for the job, they should be specified in the contract. Using hoses to access portions of the project site will often be necessary. The contract should specify how many feet of hose are needed and what percentage of the project will be applied by hose.

***Cleaning Equipment* –** The contract must state that the tank and hoses will be cleaned from all previous hydroseeding or hydromulching projects. The equipment will be inspected and, if it does not pass inspection, the contractor will be required to clean equipment at an approved offsite location.

***Weather Conditions* –** The weather conditions, based on manufacturer specifications, should be stated. The contract should specify acceptable temperature ranges and wind velocities. It should also state whether rain or freezing temperatures can occur within a specified period after application. A provision should be stated that applications will not occur on frozen ground. Some tackifiers also require that the soils be moistened before application.

***Mixing* –** The contract should state that the seeds be mixed into the slurry immediately before application. It should further state that the slurry must be applied within 30 minutes after the seeds have been placed in the tank. When the seeds are in the slurry, it should be moderately agitated only enough to mix the seeds and keep the slurry from separating.

***Application* –** The slurry should be applied at a rate that covers 85% of the soil surface. Slurry should not run off the soil. If it does, adjustments to application speeds or nozzles must be made. Figure 10.102 shows the spray pattern of two types of nozzles. Avoid applying slurry at a range that causes slurry to splash off the surface and soil to dislodge. A two pass method is preferred to obtain good seed coverage. In the first pass, 50% or less of the slurry is applied, followed by the second pass that applies the remainder of the material. Each pass is applied in a different direction (bidirectionally), which reduces the "shadow effect" created by just one pass and may serve to better lock the matrix together (Bill Mast personal communication).

***Traffic Control* –** The contract must state how traffic safety will be ensured during application. Will the contractor be required to supply signs, warning lights, or flaggers?

10.3.2.10 Keep Good Records

Hydroseeding is a complex task. Not only are several products being applied at different rates at one time, but they must be evenly applied over large complex areas. A skilled hydroseeding operator must be at the helm, and you must keep track of what is being applied and the acres on which it is being applied. This will assure that you are getting the target amount and enable accurate payment to the contractor.

Inset 10.21 – Keeping Track of the Numbers

Hydroseeding might look easy, but keeping track of the numbers is not. Most hydroseeding operators have learned to do calculations in their heads on the run. However, unless you do this kind of work all the time, you probably will not be able to manage this along with the other requirements of being a contract inspector. As fast as this operation goes in the field, you cannot afford not to have a good record-keeping system. After all, it is your responsibility to make sure that the contract is being fulfilled.

Planned Application Rates. A hydroseeding plan is developed during the preparation of the contract that locates hydroseeding areas and defines general rates of materials to be applied. The Table 1 shows how planning information for hydroseeding can be displayed. In this example, 3 hydroseeding mixes are defined by different rates of tackifier, mulch, and seed mixes in a slurry unit. Hydro mix 1 will be applied on gentle slopes requiring only a light covering of mulch (MulchRite) at 1,000 lb/ac. Hydro mix 2 is for steeper slopes and requires 2,000 lb/ac mulch and more tackifier. Hydro mix 3 is for very erosive slopes and requires 3,000 lb/ac mulch and a different seed mix. The hydro mix locations are designated on a road map. From this table, a total quantities list of materials for the project can be made by multiplying the per acre rates by the acres for each hydro mix.

Table 1

				Slurry Unit (per Acre Rates)				
				Seed	MajiTack	MulchRite	MycoAlive	SlowGro Fertilizer
Hydro Mix	Reveg Units	Seedmix	Acres	Bags/ac	Buckets/ac	Bales/ac	Bags/ac	Bags/ac
1	A2, B1	A	2.0	4	100	1,000	10	1,000
2	B1	A	5.0	4	200	2,000	10	1,000
3	D1, D2	B	3.5	4	200	3,000	10	1,000
				Total Quantities:	1,900	22,500	105	10,500

Conversions to Product Units. When you are in the field, you do not think in terms of pounds per acre because every product comes in packages. For example, MulchRite is packaged in 45 pound bales. To make it a simple, all rates must be converted from pounds per acre to product units (Table 2).

Table 2

	MajiTack	MulchRite	MycoAlive	SlowGro Fertilizer
Pounds per	50	45	10	50
Product Unit:	Bucket	Bale	Bag	Bags

Operational Plans. Table 3 converts the planned application rates to operational loading rates by 1) converting "pounds per acre" to "product units per acre" and 2) converting "product units per acre" to "product units per slurry tank." The key to these calculations is knowing approximately how many acres each slurry tank will cover. This is a function of the size of the slurry tank and the amount and type of mulch and other materials being mixed in each tank (See Figure 10.104 for calculating acres per slurry tank). In this example, it was estimated that hydro mix 1 would cover approximately 1.5 acres. Hydro mix 2 would cover half the area (0.75 ac) because twice the hydromulch is being applied. Hydro mix 3 would cover one third of the

Table 3

				Per Slurry Tank				
				Seed	MajiTack	MulchRite	MycoAlive	SlowGro Fertilizer
Hydro Mix	Tank Size	Ac/Tank	Seedmix	Bags	Buckets	Bales	Bags	Bags
1	3,300	1.5	A	6	3	33	1.5	30
2	3,300	0.75	A	3	3	33	0.8	15
3	3,300	0.5	B	2	2.0	33	0.5	10

Keeping Track of the Numbers (Cont.)

area as hydro mix 1. The math, using the tackifier MajiTack in hydro mix 1 as an example, is 100 (shaded cell in Table 1) /50 (shaded cell in Table 2) * 1.5 (shaded cell in Table 3) = 3 (circled cell in Table 3) buckets per slurry tank. Notice the difference in some of the product unit rates, such as the "SlowGro Fertilizer."

Operations Diary. Table 4 covers the minimum amount of information that must be collected during hydroseeding operations. It captures date, time, and quantity of product units placed in the slurry tank. It is also a record of the acres that were covered by each slurry tank (See Figure 10.107 for a quick way of determining acreage). Notice that the application rates in this example (ac/tank) were variable, especially for Tank 2. This is not uncommon for hydroseeding projects. At the end of each day, Table 4 is used to summarize the amount of materials used each day and to track inventory. This table is the basis for contract payment.

Table 4

								Products				
								Seed	MajiTack	MulchRite	MycoAlive	SlowGro Fertilizer
Tank	Map Unit	Date	Start	Finish	Ac/ Tank	Water (gal)	Seed Mix	Bags/ ac	Buckets/ac	Bales/ac	Bags/ac	Bags/ac
1	A2	10/18/07	9:15	9:50	1.20	3,300	Mix 1	6	2.0	33	1.5	30.0
2	A2	10/18/07	10:10	10:50	1.80	3,300	Mix 1	6	2.0	33	1.5	30.0
3	B1	10/18/07	11:20	11:55	0.70	3,300	Mix 1	3	5.0	33	1.0	15.0
4	B1	10/18/07	13:00	13:35	0.95	3,300	Mix 1	3	5.0	33	1.0	15.0
5	B1	10/19/07	14:15	15:15	0.80	3,300	Mix 1	3	5.0	33	1.0	15.0
							Toal Quantities:	21	19	165	6	105

Actual Applied Rates. Tables 5 and 6 convert what was actually applied back to pounds per acre to compare what was originally planned from Table 1. For example, 33 bales of MulchRite was applied in Tank 4 (shaded cell in Table 4). It is converted to actual pounds per acre as follows: 33 * 45 (shaded cell in Table 5) * 0.95 (shaded cell in Table 6) = 1,563 lbs/ac (circled cell in Table 6). Compared to the original plan, this was three quarters of the planned rates because the slurry tank was applied over a greater area than originally planned. For seed rates, this means that a quarter fewer seeds were applied.

Table 5

	MajiTack	MulchRite	MycoAlive	SlowGro Fertilizer
Pounds per	50	45	10	50
Product Unit:	Bucket	Bale	Bag	Bags

Table 6

								Products				
								Seed	MajiTack	MulchRite	MycoAlive	SlowGro Fertilizer
Tank	Map Unit	Date	Start	Finish	Ac/ Tank	Water (gal)	Seed Mix	Bags /ac	Buckets/ac	Bales/ac	Bags/ac	Bags/ac
1	A2	10/18/07	9:15	9:50	1.20	3,300	Mix 1	5.0	83	1,238	12.5	1,250
2	A2	10/18/07	10:10	10:50	1.80	3,300	Mix 1	3.3	56	825	8.3	833
3	B1	10/18/07	11:20	11:55	0.70	3,300	Mix 1	4.3	357	2,121	14.3	1,071
4	B1	10/18/07	13:00	13:35	0.95	3,300	Mix 1	3.2	263	1,563	10.5	789
5	B1	10/19/07	14:15	15:15	0.80	3,300	Mix 1	3.8	313	1,856	12.5	938

The records begin with the original hydroseeding prescription. These are the planned application rates of each hydroseeding material. It is not enough to know what you want as a finished product on the site; you must understand how it will be accomplished. This means that you must translate the prescribed product quantities per acre into how it will actually be applied. These calculations can be challenging, especially when the hydroseeding operation is in full swing. It is better to have some idea how this will work before you arrive in the field. Inset 10.21 is a guide through a process of determining how much of each hydroseeding material must go into a slurry tank. These calculations, along with the contract specification, become the operation plans.

During the hydroseeding operations, the contract inspector must keep track of each slurry tank that is applied. This includes the time, amount of water, quantities of products, location, acreage, and weather conditions. Calculating the acreage of each slurry tank is important in the field to assure that the rates of materials are being applied as prescribed. This can be accomplished using a method shown in Inset 10.21, Table 4. When this information is collected, the actual applied rates of materials per acre can be made using methods shown in Inset 10.21, Table 6. This will tell you how close each slurry tank came to the prescribed rates. This is important feedback for the hydroseeder operator. If the application rates were off significantly, adjustments can be made quickly. These records can be summarized at the end of the project to determine total quantity of materials used and the number of acres covered. This information can be the basis for contract payment.

10.3.3 INSTALLING CUTTINGS

10.3.3.1 Introduction

Live cuttings have a variety of uses in revegetation projects, from stream restoration to roadside stabilization. When live cuttings are used as slope reinforcement, barriers to soil movement, or integrated into retaining structures such as rock gabions, crib walls, or rock walls, they form the living component of a soil biotechnical engineering system (Sotir and Gray 1992). In slope reinforcement, live cuttings initially play a structural role by increasing soil strength and preventing surface erosion. As cuttings establish into plants, soils are stabilized through a dense network of interlocking root systems. Soils are further stabilized during the growing season as soils dry due to increased evapotranspiration and rainfall interception.

Soil biotechnical engineering techniques are well documented. Gray and Leister (1982), Sotir and Gray (1992), and Lewis (2000) are excellent sources on road and slope stabilization, and the reader should refer to Bentrup and Hoag (1998) for streamside stabilization. Section 10.2.2 discussed how to collect and evaluate live cutting quality; this section will focus on the care and installation of live cuttings to optimize the success of biotechnical engineering and other roadside revegetation projects. For simplicity, live cuttings are grouped by general application in biotechnical engineering projects: 1) live stakes, 2) live brush layers, and 3) live fascines.

10.3.3.2 Live Stakes

Live stakes are individual cuttings that are inserted into the slope to physically stabilize the soil and, with time, grow into individual plants with dense, interconnecting roots that further increase soil stability. Live stakes are used to repair small earth slips and slumps (Sotir and Gray 1992) and as pole plantings for stabilizing streambanks (Bentrup and Hoag 1998). Joint planting refers to live stakes inserted into voids or openings between large rocks. The live stakes can take root and revegetate rock riprap sites or portions of fractured bedrock (Sotir and Gray 1992). Live stakes are also used in live fascine installations and to anchor erosion mats to the soil (Lewis 2000). In gullies, draws, or intermittent streams, live stakes are placed in rows as live silt fences (Polster 1997) to slow water velocities and catch sediments and other debris. In saturated soil conditions, where excavation for brush layering or fascines is not feasible, live stakes can be densely stuck by hand.

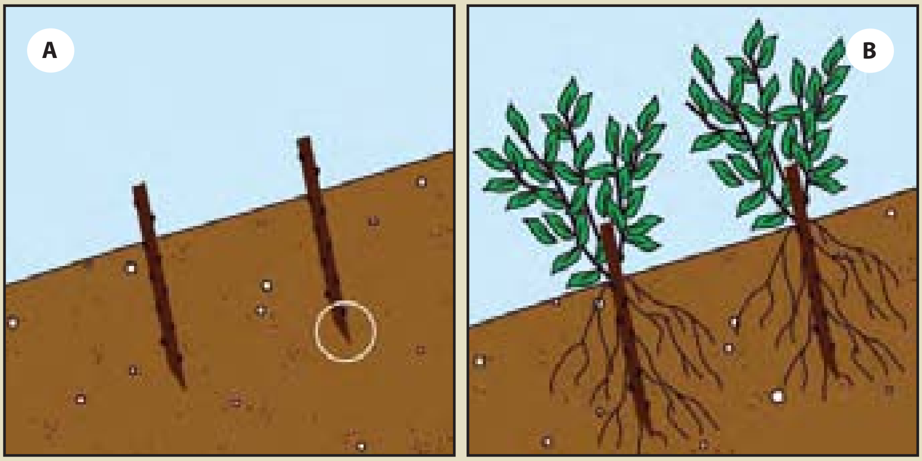
Collection **–** Live stakes are collected from the main stems of donor plants located in the wild (See Section 10.2.2) or from stooling beds in nurseries (See Section 10.2.5). The optimum period to collect cuttings is during the dormant period, after the plants have lost their leaves. If cuttings are collected outside this period, testing the viability of the cutting material is essential (See Section 10.2.2.4). It is important to collect cuttings with several dormant buds because this is where shoots will originate (Figure 10.108).

Figure 10.108 – The vertical orientation of buds on older willow (Salix spp)*.stems can be visually difficult to discern (see arrows). Keeping track of the orientation of the bud from collection to installation is very important.*

When preparing stakes, all side branches are removed, leaving just the stem. Only stems with diameters between 1 and 3 inches are used. Stems are cut into lengths of 1 to 3 feet, depending on how the materials will be used. It is important to select the appropriate cutting length. Stems that are too short will affect the success of the project, and cuttings that are too long will increase the costs of the project. During collection, basal ends of the cuttings are always oriented in the same direction to assure that the buds will be aligned. This will help avoid confusion later when the stakes are being installed. Finding the orientation of the buds is often difficult (Figure 10.108) and having to reorient in the field takes time. As individual stakes are made, the top of the stake is cut flat, while the basal end is cut at an angle (Figure 10.109). This makes the stake easier to insert into the soil and orients the live stake so the buds are facing up and away from the soil surface. If buds are facing down, the live stake will not root.

During collection, live stakes are wrapped in small bundles with twine. The size of the bundle must be light enough to be easily carried. Once the bundle size has been determined, the numbers should not vary in order to track cutting quantities. Stakes should be cut from healthy donor plants. Stems that have obvious insect or disease damage should not be used. It is often easy to forget that live cuttings are plant materials, like seeds and seedlings, and must be handled and stored with care.

***Figure 10.109 –** Live stakes are cut at an angle on the basal end (circle) for easier installation and to assure the stake is placed with buds facing up. Cuttings with buds installed upside-down will not develop into plants.*



Storage **–** It is recommended that live, dormant stakes be collected and installed the same day (Sotir and Gray 1992; Lewis 2000). This is not always possible in a road construction project. When it is not, temporary storage in Forest Service district tree coolers is an option. Temperatures in these facilities should be set below 40°F and, if humidifying equipment is available, it should be kept on high. For longer-term storage (over two weeks), cuttings should be wrapped in plastic or moist burlap to prevent the vegetative material from drying out and temperatures should be set just below freezing. Lower temperatures can result in damage and even death (Wearstler 2004). As a last resort, cuttings can be temporarily stored outside, provided: 1) daily temperatures are low (<50 °F) and humidity is high, 2) cuttings are completely wrapped in plastic, 3) temperatures will not drop below 25 °F, and 4) the site is shaded from the sun.

Preparation **–** Studies of black willow (*Salix nigra*) have shown that soaking dormant cuttings prior to installation can increase survival (Schaff and others 2002; Martin and others 2005; Pezeshki and others 2005; Pezeshki and Shields 2006). Soaking for approximately 10 days appears to be the optimum period for black willow (Schaff and others 2002; Pezeshki and Shields 2006). Soaking non-dormant cuttings, however, appears to be detrimental to survival (Pezeshki and others 2005; Pezeshki and Shields 2006). Species native to the western United States might respond similarly to the black willow. The effects of soaking can be tested in other willow species using a method outlined in Section 10.2.2.4. If live stakes are soaked in streams, it is important to be sure they are sufficiently protected from being swept downstream during high precipitation or snowmelt.

Installation **–** For most applications, live stakes are installed perpendicular to the soil surface. When installed, no more than one quarter to one fifth of the cutting is exposed (Sotir and Gray 1992; Darris and Williams 2001). Buds are always pointing up and away from the soil surface with at least two healthy buds above the soil surface. It is essential that soil be firmly packed around live stakes so there are no large air spaces surrounding the cutting. Live stakes can be installed using techniques described in Section 10.3.4, Installing Plants. These include a shovel, auger, or expandable stinger. In addition to these methods, several techniques are available specifically for live stake installation, which include a hammer, stinger, or waterjet stinger.

Hammer or Mallet. Live stakes can be pounded into the ground using a hammer or mallet. The angled basal end of the stake is placed on the soil surface and the top of the cutting is struck. A small two by four wood block can be placed on the top to absorb the impacts and reduce the risk of splintering the stake. If splintering does occur, the splintered ends should be cut (Lewis 2000). After cutting, there must still be several viable buds above the soil surface. Using a hammer or mallet works best when soils are loose and low in rock fragments. It becomes more and more difficult as rock content or compaction increases. Smaller stem diameters are often not sturdy enough for this installation method.

Stinger. The stinger is a good method for installing live stakes on rocky or compacted soils. A pilot hole is created by mechanically pushing a metal rod into the soil. A live stake is inserted into the hole and tamped to the bottom using a hammer or mallet, as discussed above. Some operators will create the hole with the stinger and, after placement of the stake, use the face of the excavator or backhoe bucket to push the stake further into the soil. The hole created by the stinger is often larger than the diameter of the stake, and the soil must be tamped in around the cutting to reduce air space and create good soil contact. A stinger can be made by welding a long piece of rebar to the bucket of an excavator or backhoe. The stinger is limited by slope gradient and terrain accessibility.

Waterjet Stinger. The Waterjet Stinger hydraulically creates a hole for installing live stakes. A pump draws water from a stream, lake, or water truck for delivery through a hose to the stinger nozzle. As the tip of the nozzle is pushed into the ground, high-pressure water is injected into the soil, creating a slurry (Figure 10.110). When the Waterjet Stinger is removed, a stake is quickly pushed into the resulting slurry at the desired depth. As water drains from the slurry, soil settles around the cutting, resulting in good soil contact.

The advantages of using the Waterjet Stinger are: 1) it is simple to operate and transport; 2) little training is necessary; 3) production rates are high; 4) holes are deep, assuring that cuttings are planted directly into a wet environment, 5) soils are saturated around the cutting for a long period of time; and 6) the soil slurry settles around the cutting, eliminating air pockets in the rooting zone (Hoag and others 2001). The disadvantage of the Waterjet Stinger is that it requires a source of water. If the project is not near a body of water, it can be brought in using a water truck or large water storage containers placed in the back of a truck (Figure 10.111). The

***Figure 10.110** – The Waterjet Stinger (A) injects high-pressure water into the soil, turning it to a slurry (B) into which a live stake can be inserted (Photos courtesy of Chris Hoag).*

Waterjet Stinger is also limited by the amount of rock present in the soil. This equipment does not work well in soils containing gravels, cobbles, and boulders that obstruct the downward movement of the probe (Hoag 2007). Sandy soils drain quickly, so installation of cuttings with the Waterjet Stinger must be done quickly and with a little more effort. Steep slope gradients and rough terrain also limit equipment and the transportation of water. For more information on the Waterjet Stinger refer to Hoag and others (2001).

Expandable Stinger. The expandable stinger can install live stakes into all soil types and soil conditions, from rocky to compacted. It can plant long cuttings (> 4 ft), and stems of most diameters (including very small diameters). The stake is placed into the stinger, which is inserted into the soil and released, leaving the cutting at the desired depth (See Section 10.3.4.3, Select Planting Tools and Methods). This installation method can leave large air spaces around cuttings. It is therefore recommended that soils be tamped around the cutting after placement.

Hand-Sticking. Hand-sticking is appropriate in areas where soils are mucky or saturated, including recent landslides and wetlands, and cuttings can easily be inserted into the soil. Because this installation method can be done quickly, areas can be planted at very high densities (Figure 10.112).

***Figure 10.111** – A 250-gallon water tank with pump can be installed in the bed of a pickup truck to supply water for Waterjet Stinger sticking.*

Figure 10.112 – *Hand-sticking cuttings at high densities is an option for saturated soils where the soils are too wet for installation of fascines or brush layers. This photograph shows leaves forming on cuttings several months after installation.*

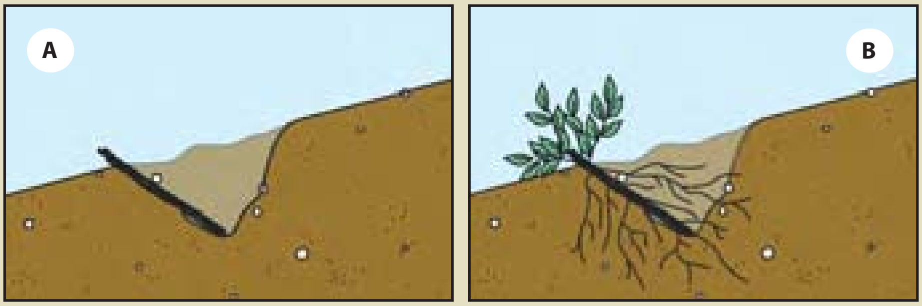
10.3.3.3 Live Brush Layers

Live brush layers are cuttings that are spread on excavated benches and covered by soil (Figure 10.113). This practice is used in several biotechnical engineering applications, including brush layers and modified brush layers. Constructing brush layers is a three-step process in which contour benches are excavated, live branches are spread across the bench surface, and branches are covered with soil from constructed benches directly upslope. The process begins at the bottom of the slope and is repeated until the entire slope is installed with brush layers. In a modified brush layer system, the brush layers are resting on, and supported by, logs or live fascines (Sloan 2001).

Brush layers and modified brush layers increase slope stability and reduce erosion by breaking slope length, reinforcing soil, trapping sediment, increasing infiltration, acting as horizontal drains, and reinforcing soil as cuttings develop roots (Sotir and Gray 1992). Live brush layers can also be used to vegetate crib walls, rock gabions, and rock walls. In this application, live branches are placed on benches that are created as these structures are built. For crib walls (Inset 10.22), live layers are placed on the bench created behind each layer of logs; in rock gabions, live layers are placed on each layer of gabion baskets.

Collection – Materials for live layering are obtained from branched cuttings collected in the wild or from stooling beds. Stems up to 2 inches in diameter can be used (Sotir and Gray 1992). The basal end of the cuttings are always oriented in the same direction during collection and bundling. Cuttings for brush layers should be long enough that the growing tips are just exposed at the soil surface, while the basal portion of the cuttings reach to the back of the bench (Sotir and Gray 1992). For rock gabions, rock walls, and crib walls, cuttings should be

Figure 10.113 – *Live brush layers are cuttings that are placed on benches and covered with soil (A). The basal end of the cuttings should extend back to the base of the bench, and the growing tip should just show out of the soil. When placed on the contour and at regular intervals, live brush layers form a network of roots and vegetation that tie the slope together in a series of strips, increasing slope stability and reducing erosion.*



Inset 10.22 – When Should Seedlings or Rooted Cuttings be Substituted for Live Cuttings?

Live cuttings are widely used in biotechnical engineering projects. Sometimes, however, it is more practical to substitute rooted cuttings or seedlings in place of live cuttings. This is especially the case when the road project calls for cuttings to be planted in the summer or fall, when dormant, live cuttings are not available, or when live cutting material is not available in large enough quantities.

For example, a road near a wild and scenic river is being widened. Biotechnical engineering techniques using live willow cuttings are being planned for retaining walls to increase slope stability in areas adjacent to the river. The design looks good on paper (A). However when discussing the details with a revegetation specialist, question arises: where will the cuttings be collected and what time of year will the willows be installed? Upon inventorying the willow stands on the district, they learn there is not a supply of willows great enough to meet the needs of the project. To obtain this volume and size of cuttings would require the establishment of stooling beds at a nursery (See Section 10.2.5), which would take at least two years prior to project implementation. More disturbing, they learn that the contract can only be implemented in the summer due to water quality and wildlife restrictions. While some cuttings installed in the summer would sprout, most would not, as was determined through rooting potential testing (See Section 10.2.2.4). Referring back to the project objective, the design engineer and the revegetation specialist realize that going ahead with the project, as designed, would compromise revegetating the retaining wall. The decision was made to adopt an alternative design to install rooted cuttings grown in long tubes (at a nursery) instead of unrooted cuttings. The rooted cuttings would be planted at very high densities where the brush layers were to be installed (Figure B). Since only a small amount of cuttings would be necessary to start rooted cuttings in containers at the nursery, there was no need to develop stooling beds, eliminating the extra time and costs to produce these plant materials.

The stems of the long-tube rooted cuttings can be set back several feet into the soil (see circle in Figure B) as long as a portion of the foliage is above ground. This will add length to the rooting area and the stems will initiate roots (C).

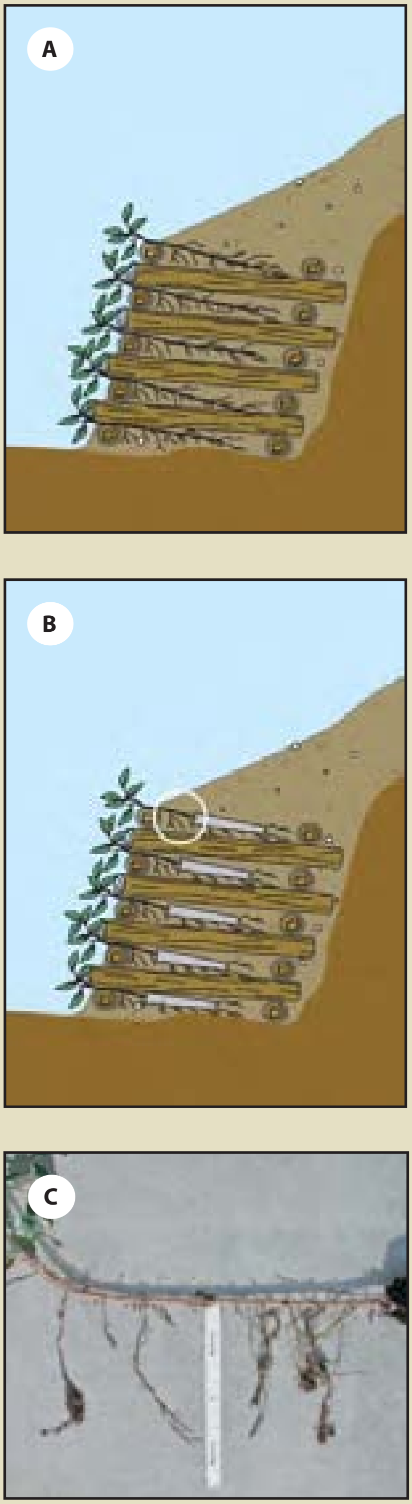
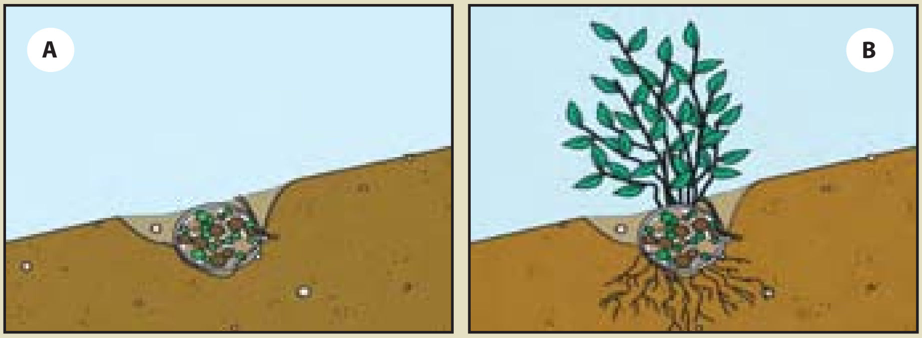


Figure 10.114 – *Live fascines are long bundles of cuttings placed in trenches constructed perpendicular to the slope. The bundles are placed in contact with the soil, with the upper portion of the fascine covered by a thin layer of soil (A). Fascines initiate shoots and roots in the spring, and are established by early summer (B).*



long enough to extend into soil or backfill behind the structures. During collection, cuttings are placed in bundles and secured with twine. Bundles should be light enough to carry. The optimum period to collect cuttings is during the dormant period, when the plants have lost their leaves. If cuttings are collected outside of this period, then testing the viability of the cutting material is essential (See Section 10.2.2.4). Fine branches dry out quickly if exposed to warm dry temperatures. Cuttings must be protected during transportation, storage, and handling to avoid drying.

Storage – See discussion under Live Stakes, Section 10.3.3.2.

Installation – Branched cuttings are laid out on benches so the basal end of the cutting reaches to the back of the bench and the growing tips extend just beyond the front. Soil is placed over the cuttings and tamped to assure there are no large air spaces. Excessive compaction is unnecessary for plant establishment and is often detrimental for long-term plant growth (See Section 5.3.3). The material used to cover live branches in or behind crib walls, rock gabions, and rock walls is often low in water-holding capacity, nutrients, and organic matter. Soil amendments, such as compost, can be incorporated into backfill material to improve water-holding capacity and to serve as a long-term source of nutrients and organic matter. These amendments can increase establishment and improve plant growth (See Section 10.1.5, Organic Matter Amendments). Waiting until after the construction of crib walls, rock gabions, and rock walls to amend the soil is not practical or feasible.

10.3.3.4 Live Fascines

Live fascines are cuttings bound together to form a long continuous bundle (Figure 10.114). When installed on the contour, live fascines slow runoff, increase infiltration rate, capture sediments, reduce slope length, and revegetate the site (Sotir and Gray 1992). Live fascines have a good potential for quick establishment because of the high density of buds near the surface of the soil. Live fascines can quickly send out shoots and roots early in the growing season and become established before summer (Figure 10.114).

Fascines are used in the construction of live pole drains to drain saturated slopes, small slumps, or gullies (Polster 1997). Live pole drains are designed to intercept surface water from unstable slopes or seepage areas, and transmit it through a system of interconnecting bundles to more stable areas (See Section 5.7.3). The constant supply of intercepted water encourages vigorous growth of the cutting material into a continuous stand of vegetation. Fascines are also used as the base or support in the construction of modified brush layers. Live fascines have great potential for establishment because of the high density of buds just under the surface of the soil. These buds can emerge quickly in late winter and early spring. Because they are installed at the soil surface, live fascines are more prone to drying out than live brush layers or live stakes. For this reason, live fascines are more successful on moist sites or in conjunction with live brush layering or live staking.

Collection – Branches and stems up to 2 inches in diameter are collected from the wild or from stooling beds and gathered to form a long continuous bundle. Fascines vary in length

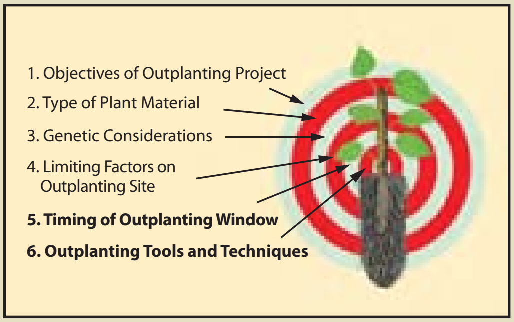


***Figure 10.115** – The final two steps of the Target Seedling Concept, the Outplanting Window and Planting Tools and Techniques, must be considered before initiating planting projects (adapted from Landis and Dumroese 2006).*

from 5 to 30 ft, and from 6 to 8 inches in diameter. For large projects, constructing a series of sawhorse-type structures makes this operation easier and more efficient (Sotir and Gray 1992). At frequent intervals, bundles are secured with twine to hold the fascines together. Cuttings should be collected during the dormant season, when the plants have lost their leaves. Fine branches dry out quickly if exposed to warm dry temperatures and must be protected during transportation, storage, and handling.

Storage – See discussion under Live Stakes, Section 10.3.3.2.

Installation – Prior to installation, trenches should be created at the proper depth so the top of the fascine is flush to the surface of the slope when installed. The shape of the trench should allow soil contact with all portions of the bundle. Soil is tamped down around the sides of the bundles to assure soil contact, and the upper fifth of the bundle is covered by a thin layer (<1 inch) of soil. A very small portion of the fascine should be exposed, but not enough to dry the stems. If the fascine is buried too deeply, vegetative growth will be restricted.

10.3.4 INSTALLING PLANTS

10.3.4.1 Introduction

Although a wealth of information exists about planting for reforestation, very little information has been published about planting nursery stock on roadsides. Several references can be found discussing harsh site reclamation. Ashby and Vogel (1993) is an excellent source for planting on restored minelands.

Before beginning a planting project, the revegetation plan and plant production contract should be reviewed carefully, as should the Target Seedling Concept (Figure 10.115) which was considered during the planning process (See Section 6.4). The first four steps were covered when plants were ordered during the planning process. The timing of the outplanting window and planting tools must be considered at this time.

Timing of the Outplanting Window – The outplanting window is the period of time in which environmental conditions on the outplanting site are most favorable for survival and growth of nursery stock (Figure 10.116). The outplanting window is usually defined by limiting factors, and soil moisture and temperature are the usual constraints. In most of the continental United States, nursery stock is outplanted during the rains of winter or early spring when soil moisture

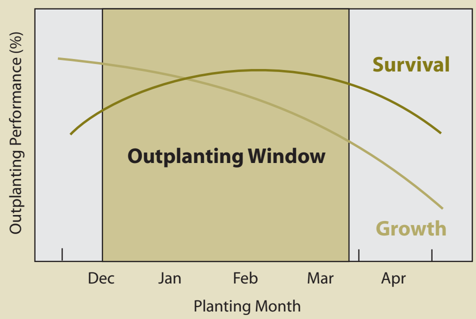


***Figure 10.116** – The best time to plant your project site (the "outplanting window") will depend on local weather and soil moisture conditions. In the Pacific Northwest, this is typically during late winter or early spring, when soil water content is high and atmospheric drying potential is low (modified from South and Mexal 1984).*

***Figure 10.117** – This type of spreadsheet helps calculate how many plants of each species are needed and should be developed for each planting area. This example includes quaking aspen (POTR5), ponderosa pine (PIPO), and Saskatoon serviceberry (AMAL2), but can be extended to accommodate more species.*

Revegetation Unit		Plant Species			Units	Definition
2		PIPO	POTR5	AMAL2		
A	Planting area:	0.75			acres	Area that will be planted
B	Target plant spacing:	9	14	20	feet	Desired distance between established plants
C	Ave. survival potential:	95	70	70	%	Percent of seedlings that survive after one growing season
D	(43,560 * A) / (B * B) =	403	167	82	plants	Desired number of established plants after one growing season
E	D * (100 / C) =	425	238	117	plants	Number of nursery plants that need to be planted

is high and evapotranspirational losses are low. Fall outplanting is another option on some projects, especially when dormant and hardy plants can be installed just before the normal rainy season begins. Planting during the summer is usually discouraged because the nursery stock is not dormant and will experience severe transplant shock. If nursery stock is carefully handled and plants can be irrigated, then summer plantings are possible.

Planting Tools and Techniques – Nursery stocktype and the conditions on each outplanting site must be considered before planting begins. All too often, planters develop a preference for a particular planting implement because it has worked well in the past. However, no one tool will work for all types of nursery plants and under all site conditions. Size of nursery stock, in particular the depth and width of the root plug, is the critical consideration. Tall pots, for example, have an unusually deep root plug, which makes them difficult to plant properly with standard tools. For some types of plants and especially for large planting projects, it may be necessary to buy or rent specialized equipment, which must be secured in advance. The planting tools recommended for roadside revegetation projects are discussed in Section 10.3.4.3.

10.3.4.2 Define Planting Areas

When construction is completed, the project site is assessed for planting. A detailed map showing the exact planting locations and conditions is developed by reviewing each location on the ground. Each area should be identified on a map and described in a spreadsheet by:

- Planting area acreage,
- Planting patterns,
- Plant spacing (density),
- Survival potential, and
- Species and stocktype mix.

***Figure 10.118** – This spreadsheet is a practical way to calculate the area of each planting unit.*

	A	B	C	D		D
1	Station	Slope Length (m)	Distance Between Stations (m)	Area (m^2)		
2	2 + 1000	3	20	60		= B2 * C2
3	2 + 1020	4	20	80		= B3 * C3
4	2 + 1040	6	20	120		= B4 * C4
5	2 + 1060	7	20	140		= B5 * C5
6	2 + 1080	6	20	120		= B6 * C6
7	2 + 1100	4	20	80		= B7 * C7
8	2 + 1120	2	20	40		= B8 * C8
9						
10		Totals	m^2	640		= SUM(D2:D8)
11			ft^2	6,888.90		= D10 * 10.76391
12			Acres	0.16		= D11 / 43,560

With this information, a planting strategy can be developed for each planting area using calculations similar to those shown in Figure 10.117.

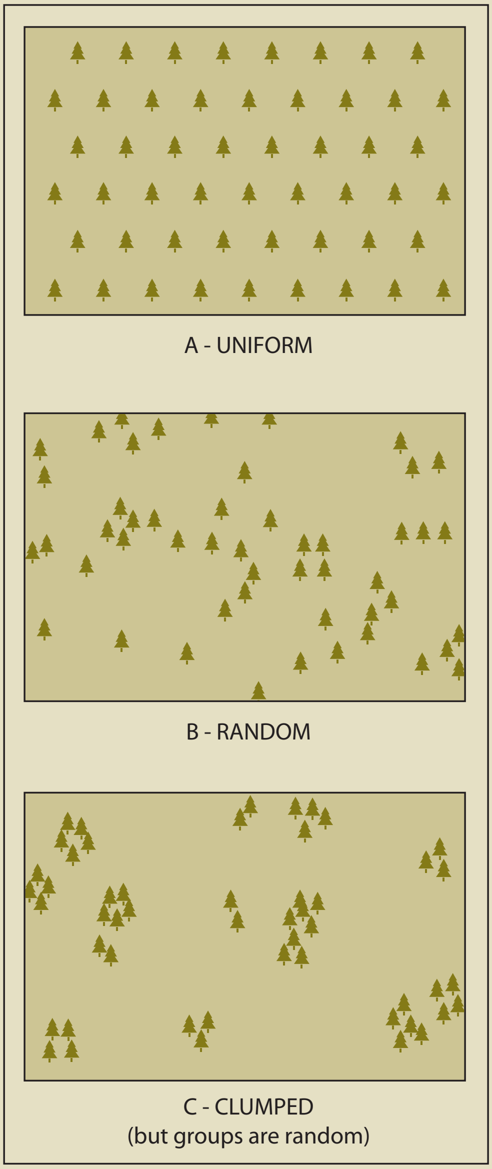
Size of Planting Areas **–** The first step is to measure the area of each planting unit. Although they could be calculated from blueprints, the true planting areas should be measured on-site. A practical method is described in Figure 10.118.

Planting Patterns **–** The pattern at which nursery stock is planted is critical for creating a more natural and visually pleasing roadside experience. Most planters have learned to install plants at uniform spacing and in rows (Figure 10.119A). Although uniform patterns ensure that all plants have equal growing space, it is not natural. Planting seedlings in groups (Figure 10.119B) or clumps (Figure 10.119C) is more visually appealing and more ecologically functional.

More specific considerations about planting patterns are based on project objectives and site characteristics of the area. A typical example would be using plants to screen potentially dangerous or visually sensitive areas, such as large cuts and fills or obliterated roads. Determining where trees or shrubs are to be planted to meet these objectives can only be accomplished by driving the newly constructed road and making these decisions in person.

Plant Spacing **–** The planting spacing or density (See Section 10.2.6.4) will determine how quickly an area will be screened by vegetation. The higher the density, the more plants are required. Selecting the appropriate density must be based on the existing vegetation density recorded at reference sites, as well as both short- and long-term project objectives. It must also be based on the expected survival rates of the planted stock, since not all planted stock will survive.

Figure 10.119 **–** *The objectives of the outplanting project and desired appearance affect planting patterns. If the objective is rapid growth and quick site coverage, the plants can be regularly spaced (A). However, plants spaced in a more random pattern mimic natural conditions (B), and a random clumped pattern where different species are planted in groups is often the most natural appearing (C) (adapted from Landis and Dumroese 2006).*



Survival Potential **–** Each planting area must be assessed for its unique site characteristics, such as rock content, soil depth, accessibility, steep slopes, and poor accessibility. These will determine the stocktype and species selection, method of planting, and the difficulty of transporting large plants to the site. The identified site limitations will determine the expected survival rates; target survival rates should be at least 70% to minimize the costs of site preparation and anticipated replanting.

Species Mix and Stocktype **–** Each planting area will have a different mix of species and stocktypes based on the site characteristics and project objectives defined during the planning stages. This is a refinement of those plans, based on site specific evaluation of the area. Trees and other large woody plants are considered “keystone species” because of their sheer size and longevity. These structurally and functionally dominant plants play a pivotal role in restoration plantings because they generate physical structure and create ecological niches for many other species. This fosters the in-seeding of other plants, resulting in a more natural and visually appealing landscape.

10.3.4.3 Select Planting Tools and Methods

One planting method will rarely work for all planting areas in a revegetation project. Roadside sites offer some serious challenges to planting nursery stock, most notably highly compacted soils and often a high percentage of rock. Road projects create the opportunity for unique situations such as planting islands.

The most common type of planting method is manual planting using a shovel. Recent developments in mechanized planting equipment have increased tools available. The most common types of planting tools for roadside revegetation sites are described below:

Shovel **–** The versatile “tile spade” shovel (Figure 10.120A) is the first choice for compacted soils and stocktypes used in roadside revegetation. Forestry supply companies sell a specialized planting shovel with a 14 by 5 inch blade, a welded reinforcement plate on the back of the blade (Figure 10.120B), and rubber padded footplates (Figure 10.120C). Shovels work well when planting both bareroot and container stock, as well as bulbs and other plant materials that do not require holes deeper than one foot. Working the shovel blade back and forth breaks up compacted soil and can create a planting hole for large container stock (Figure 10.120D). Sites must be accessible for hand planters, and the soils not too rocky or shallow. Very steep slopes (1:1 or greater) make shovel planting very slow and difficult.

Power Auger **–** Power augers can be an excellent and efficient way to excavate holes for planting (Figure 10.121A). Many types of augers are available: 1-person operated, 2-person operated, and a chain saw modification. A wide variety of auger sizes means that this one implement can work for many stocktypes. Augers are particularly good for large container stock. For example, a four-inch auger bit will create planting holes that will just fit the root plug of a “Tall Pot” container plant, ensuring good root-to-soil contact (Figure 10.121B). In a comprehensive review of planting tools, Kloetzel (2004) concluded that, when container size is larger than 336 ml (20 in^3), power augers will boost production under most soil conditions. It is most efficient to have one person operating the auger, with several people planting behind him/her. Auger planting is effective on restoration sites because one person determines the location and pattern of the planting holes. Production rates are reduced with rocky or compacted soils, but a drill

Figure 10.120 **–** *Specialized “tile spade” shovels are ideal for planting a wide variety of nursery stock on restoration sites (A). Commercial planting shovels feature a reinforced blade (B) and rubber-padded footplates (C). Working the long shovel blade back and forth breaks up compacted soil and creates planting holes deep enough for large container stock (D).*

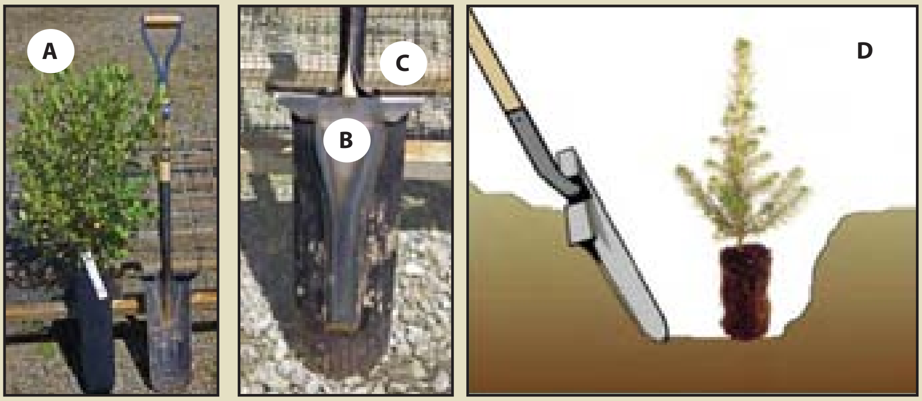


***Figure 10.121 –** Power augers are effective because one trained operator determines the depth and spacing of the planting holes (A). Auger bits come in a variety of sizes to accommodate the large stocktypes favored in restoration plantings (B).*

auger with a special bit has been developed for planting large container stock in rocky soils (St. Amour 1998).

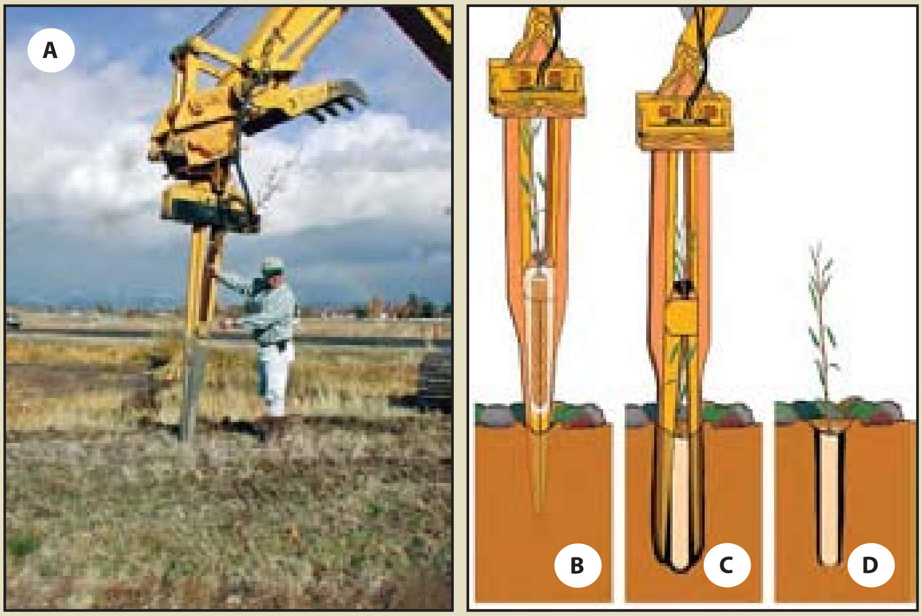
Expandable Stinger – Specialized planting equipment is needed for the rocky and steep slopes that are often found along forest roads. The original stinger was a pointed metal bar that was hydraulically forced into the soil to plant willow and cottonwood cuttings. The expandable stinger is a recently developed planting device attached to the arm of an excavator (Figure 10.122) that creates a hole and plants the seedling all in one operation. The planting head is composed of two parallel steel shafts, which are hinged in the middle to open and close in a scissor-like manner. Each shaft is constructed to create a long hollow chamber between them when closed. The opening and closing of the shafts are hydraulically driven. When the shafts are closed, the stinger comes to a point and is pushed into the soil by the force of the excavator arm. A long hardwood cutting or container plant is placed into the chamber. The expandable stinger is maneuvered to the planting spot, where the beak is inserted into the soil. When the beak opens, the seedling drops to the bottom of the hole leaving, the seedling in place (Figure 10.122B-D).

Two expandable stinger models are currently in use. The single-shot model inserts plants one at a time and averages between 50 to 80 seedlings per hour. The 50-shot model contains a rotary magazine that can hold fifty plants of up to three different species and can double the planting rate of the single-shot model (Kloetzel 2004).

The advantage of this equipment is that it can reach very steep cut and fill slopes, sites that are inaccessible by other planting methods. Smaller excavators can reach 25 feet, while larger machines extend planting up to a 50 foot radius, which is adequate for most cut and fill slopes. This equipment can also plant in very rocky soil conditions, including rip-rap and gabions, and can insert plants up to 6 feet. With the typically compacted soils on roadside sites, the action of the beak of the expandable stinger breaks up the compaction around the planting hole. While soil typically falls back around the root plug after the expandable stinger has planted the seedling, it is still important to determine whether additional soil needs to be filled and tamped around the plant. Poor soil contact with the root system can reduce survival and growth during establishment.

The major drawback to the expandable stinger is the expense. Because of the high hourly rate of an operator and equipment, the expandable stinger must be working at full capacity at all times. Good planning is essential. This means that all the planting sites are laid out before the

__Figure 10.122 –__ The expandable stinger is operated by placing a long container or hardwood cutting into the chamber (A). The arm of the excavator pushes the point of the stinger into the soil to the appropriate planting depth for the root system (B) and the beak opens, shattering the soil (if it is compacted) and creating a hole (C). The stinger is removed and the plant remains in place as soil collapses around the sides of the plug (D).



equipment arrives, there is a clear understanding of species mix and planting for each planting area, seedlings are on the site and ready for loading into the equipment, and there is enough personnel to keep the equipment going. In a well-planned operation, the expandable stinger can plant up to 200 seedlings in an hour. In addition to the hourly operating costs, the mobilization costs can be very high, especially if the excavator and expandable stinger must be transported across several states. These costs must be spread across all seedlings being planted for a true cost. The more seedlings that are planted by the expandable stinger at one construction site, the less it will cost per planted seedling. Larger planting projects (>1,500 seedlings) spread these costs over more seedlings and make expandable stinger projects economical.

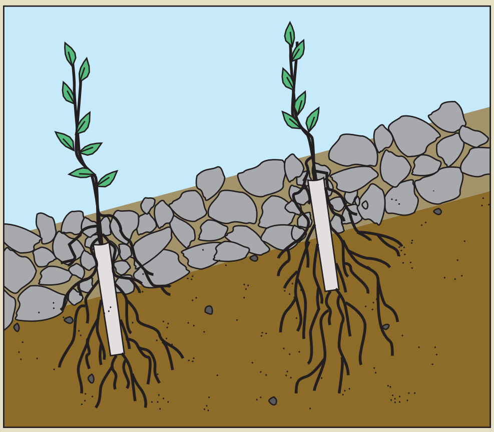
Pot Planter – The pot planter is a modification of the waterjet stinger (See Section 10.3.3, Installing Cuttings) that creates planting holes large enough for container plants. Like the waterjet stinger, it draws water from a water source (e.g., a lake, stream, water truck) and hydraulically creates a planting hole as the tip of the high pressure nozzle is pushed into the soil (Figure 10.123A). The pot planter has 3-inch vanes attached to the sides of the nozzle, which create holes large enough for containers up to one gallon (Figure 10.123B). The hole that is created by the pot planter is actually a soil slurry that is displaced when the root plug is pushed into it at the desired planting depth. Once the water drains from the slurry into the surrounding soil, the soil settles in around the root plug, assuring good soil-to-root contact.

The advantages of using a pot planter include: 1) container plugs are thoroughly moistened at outplanting, 2) there are fewer air pockets in the soil and better root-to-soil contact, and 3) soil around the planting hole is moistened, allowing roots more time to move out of the plug and into the native soil. These advantages create the opportunity for earlier fall planting dates, even as early as late August to early September in some areas. The earlier the fall planting, the greater the chance for rooting to occur before winter sets in. This rooting will be in addition to the root growth that occurs the following spring and can make the difference in whether a seedling survives the first growing season. Large containers can be planted quickly at a rate of approximately one plant per minute (Hoag 2006). The pot planter is limited by the same factors as the waterjet stinger, which include steep slope gradients, inaccessibility, high soil rock content, and poor water source availability.

__Figure 10.123 –__ The pot planter creates a planting hole by injecting high pressure water into the soil (A). Once the soil is liquefied, the container is pushed into the soil to the appropriate depth (B).

Planting into Engineered Structures – There are occasions when seedlings will be planted as engineered structures are being built. These structures include vegetated gabion walls, riprap, and retaining walls (See Inset 10.22 in Section 10.3.3). Planting must be well planned and integrated into the construction schedule. Since road construction often takes place in the summer when plants are in full growth, special handling methods and irrigation must be implemented during installation to assure optimum seedling establishment (Figure 10.124). Installing plants into riprap, for example, requires good planning and integration into construction activities. Drawings and a set of planting instructions are essential. Seedlings are partially planted in the existing soil and partially in riprap. Riprap and soil is hand placed around the seedling plug to assure good root–to-soil contact and that the seedlings are handled with care. The remainder of the riprap is placed and the seedlings are irrigated. Each vegetated engineered structure will require different sets of instructions and drawings that are specific to the objectives and environmental conditions of the site.

__Figure 10.124 –__ Engineered structures of gabions and riprap require tall nursery stock and special installation techniques. When properly done, however, plants survive and grow well and greatly increase the visual appearance of the structure.



10.3.4.4 Assess Plant Inventories

Depending on the size and scope of the project, there may be many combinations of species, seedlots, and stocktypes being grown at one or more nurseries. Seedling inventories from all nurseries where your stock is being grown must be consolidated into one list. Each nursery will supply a list of the quantity of seedlings in each seedlot that meet the contract specifications. Do not be surprised if this list does not exactly meet your original order. It is rare that the original seedling order ever gets filled exactly as requested. Some seedlots grow well, while others grow poorly, and this is reflected in the seedling inventory. You will find there are more seedlings in one seedlot and less in another.

Plant inventories do not always give the full story about seedlots. Prior to putting together a planting plan, a visit to the nurseries will give a full picture of the status of each seedlot. Stressed seedlings, poor roots, root-bound seedlings, disease, and other problems can only be realized by visiting the nursery months before plants are received. The visit to the nursery is not always a negative fact finding mission. It should be approached as a problem-solving trip. For example, an inventory might indicate that certain seedlots do not meet size specifications. A closer review at the nursery may show that many of the seedlings that do not meet size specifications would be suitable in certain planting areas. If inventories are low, discussions with the nursery manager might bring up the possibilities of substituting surplus seedlots from other clients for the downfall in your inventory.

10.3.4.5 Match Inventories to Planting Area

At this point, the information developed during the location of planting units, including seedling density, species, and stocktype, must be reevaluated in light of the newest seedling inventory. In other words, the seedlings from the inventory must now be divided between planting areas in a manner that still meets the project objectives.

Using the spreadsheet in Figure 10.125 is a simple way to reconcile the differences between the plants needed at each planting area and the plant inventory. In this example, three planting areas are defined (A1, A2, and B). For each planting area the number of plants of each species/stocktype are listed. The planned needs are summarized in Line A. When the seedling inventory (Line B) is received, it is discovered that there will not be enough ponderosa pine (PIPO) or quaking aspen (POTR5) to meet the planned needs. The deficits are circled in Line C. In this example seedlings can either be obtained from other sources, or the plant needs can be adjusted downward. In this example, the PIPO and POTR5 were adjusted downward because no substitute trees could be found to make up the difference. AMAL2 (Saskatoon serviceberry) was adjusted upward as a partial substitution for the shortfall of tree seedlings. Planting spacing was recalculated from Figure 10.117 with a resulting increase of approximately 1 ft for both PIPO and POTR5. The extra PUTR2 (antelope bitterbrush) and PREM (bitter cherry) were not planted (Line F), but surplused to a local landowner. Many more rows and columns can be added to this spread sheet to accommodate more species and planting areas.

***Figure 10.125** – Spreadsheets are a handy way to keep track of nursery orders and adjust plant inventories to planting needs.*

Planned Seedling Needs

		Species & Stocktype				
		PIPO	POTR5	AMAL2	PUTR2	PREM
	Planting Areas	2 Gal	1T18	1T12	1STP	1STP
	A1	425	238	117		
	A2	75	25	35	100	
	B		275			50
A	Planned Needs	500	538	152	100	50
B	Seedling Inventory	400	435	200	125	75
C	Difference	-100	-103	48	25	25

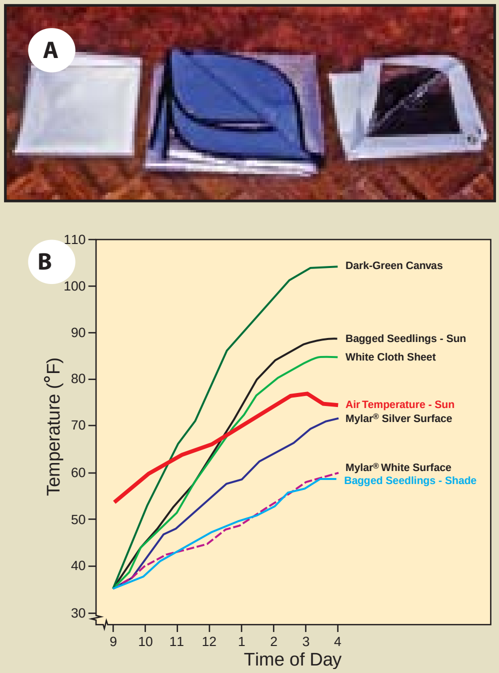
Adjusted Seedling Needs

		Species & Stocktype				
		PIPO	POTR5	AMAL2	PUTR2	PREM
	Planting Areas	1 Gal	1T18	1T12	STP	STP
	A1	350	200	155		
	A2	50	10	45	100	
	B		225			50
D	Adjusted Needs	400	435	200	100	50
E	Seedling Inventory	400	435	200	125	75
F	Difference	0	0	0	25	25

10.3.4.6 Transport Plants

The delivery of seedlings to the planting site is not generally the responsibility of the nursery. It can be an item in the seedling production contract, a separate transportation contract, or you can transport them yourself. Whichever way you decide, remember that seedlings can be easily damaged during transportation by poor handling, hot temperatures, or drying conditions. Plants that have been packed in bags or boxes are protected from drying conditions and can be transported in most vehicles. If containers are transported in open pickups, they should be covered with a space blanket or special tarps to moderate temperatures and minimize the potential for desiccation (Figure 10.126). Specially-constructed Mylar® tarps can be purchased from forestry or restoration supply companies.

***Figure 10.126** – During transportation and on-site storage, nursery stock should be covered with special reflective tarps (A) which have been proven to reduce temperature buildup (B).*



Plants that have been kept in freezer storage should be thawed prior to transportation and planting. While small container stock has been shown to have satisfactory survival when planted frozen, there is no indication that large stock will perform the same. Once frozen seedlings have been thawed or cooler-stored seedlings have been allowed to warm, they should be planted immediately. Seedling viability will decrease if they are placed back into cold storage for more than a few days.

Plants that have not been packed in storage containers must be transported in enclosed units. Transporting plants in open vehicles, such as pickups, exposes foliage to strong, drying winds which can unduly stress the plants. Large container plants typically stand 2 to 4 feet tall (including the container) and require transportation with enough space to accommodate the size.

10.3.4.7 Develop Planting Contract

The following discussion outlines some of the basic components that should be addressed in a planting contract.

Location – A map of the planting areas should be included in the contract.

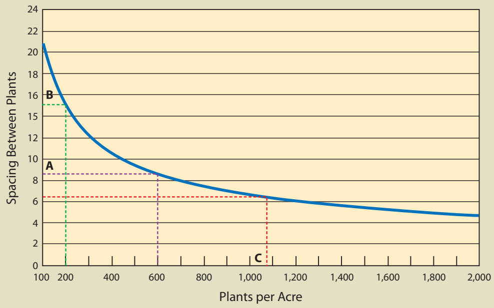
Planting Quantities – The quantity of species, by stocktype, must be presented for each planting area.

Planting Method – There might be several planting methods which should be indicated for each stocktype and planting area.

Plant Spacing Requirements – For each planting area, describe or define the plant spacing at which each species will be planted. Calculations to determine the proper spacing between plants was presented in Figures 10.117. Approximate distance between plants can be determined graphically by knowing the target plants per acre, and, in reverse, the plants per acre can be determined by knowing the target spacing between plants (Figure 10.127). For example, if the plan calls for a density of 600 seedlings to be planted per acre, the spacing between plants would be around 8.5 feet (Figure 10.127A). If the plan calls 600 seedlings to be planted in planting pockets of three plants per pocket, there would be 200 planting pockets spaced approximately 15 feet apart (Figure 10.127B). In another example, if you want to know the number of seedlings to order for a given area with a target spacing of 6 feet, the number of plants required would be just under 1,100 seedlings (Figure 10.127C).

These spacing requirements are an average. Depending on the plantability of a site, the specified average spacing may vary up to 25% in any direction to find a suitable planting spot. Where an unplantable spot is encountered, the planter will plant in the closest plantable spot. Whenever possible, plants should be installed next to stumps, logs, or other obstacles that provide partial protection from sun, wind, and animals. If planting islands are designed into the planting areas, each island should be marked within the planting area by the contract inspector and the species mix should be stated in the contract.

Figure 10.127 – *Approximate distance between plants can be determined from this graph by knowing the target plants per acre, and, in reverse, the plants per acre can be determined by knowing the target spacing between plants.*



Handling Care – Plants must be handled with care to prevent damage to roots and foliage. Seedlings must not be thrown, dropped, hit, or otherwise mechanically impacted. Extracting the root plug from the container must be done gently, avoiding excessive force when pulling the seedling from the container. Seedlings should not be removed from containers until the hole is excavated. The container is then removed, and the seedling is quickly planted. Excessive exposure of the root system to the air will decrease seedling survival and growth (Greaves and Hermann 1978).

Root Pruning – The bottoms of some containers are poorly designed, causing roots to circle or build up at the bottom of the pot (Figure 10.128A). These damaged roots must be cut prior to planting to prevent potential root strangling, especially for tap-rooted woody species (Figure 10.128B). Root pruning is best accomplished at the nursery, but must be stated in the growing contract to cover the added expense. Pruning in the field is not recommended because of the increased root exposure. However, it may be necessary when nursery stock arrives with constricted roots.

Figure 10.128 – *Roots will circle and accumulate at the bottom of some container types (A), especially if the stock has been held too long. Pruning these roots at planting will ensure that new roots will promptly grow out into the surrounding soil (B).*

__Container Moisture –__ Root plugs that are dry must be thoroughly moistened prior to planting. Irrigating seedlings at the nursery several days before shipping and again on the day of shipping assures that root plugs are completely wet. These instructions must be conveyed to the nursery manager prior to picking up the seedlings. Provisions should be in the contract that addresses the need for wetting root systems should they be dry at the time of planting. Wetting root plugs can be accomplished by dipping seedling containers into a large water container, such as a cattle trough or trash can, prior to planting. Planting seedlings using the pot planter assures that the root plugs are wet at planting.

__Temporary Storage –__ If container plants cannot be planted in one day, they can be stored in the field in a well-sheltered area protected from the sun and animals. Reflective tarps are recommended to keep plants cool and moist during on-site storage (Figure 10.126). If container plants are left out for several days, the root plug should not be allowed dry out. If they do lose moisture, the containers must be irrigated prior to planting. Plants that have been extracted and placed in storage boxes or bags should not be left on–site, but returned to a local cooler for storage.

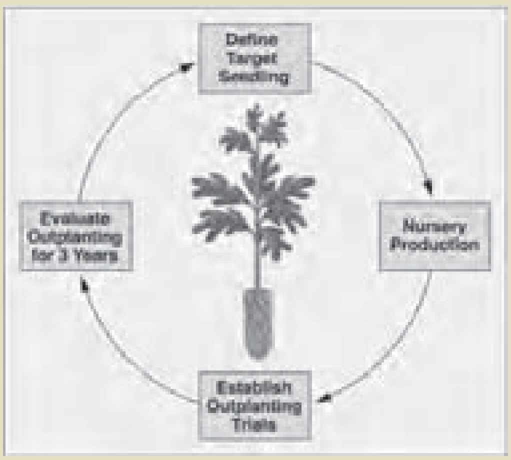
__Planting –__ Prior to preparing the planting hole, the planters must clear the surface of the planting spot of all limbs, logs, snow, duff, litter, rocks, and other loose debris. If sod, crowns of living plants, and roots are present, they must be scalped down to moist mineral soils. Clearing and scalping dimensions must be stated in the contract. Planting holes shall be located near the center of the prepared planting spot and they should be dug vertically rather than perpendicular to the ground surface. The planting hole should be three to four inches deeper than the total length of the root system or root plug, and wide enough to fully accommodate the width of the root system. Seedlings should be placed in the hole so that the cotyledon scar (the bump or constricted area on the seedling stem that is the transition from the root system to the stem) is one inch below the ground line. Species that can be rooted from cuttings can be planted deeper, since portions of the stem will root when buried. The root plugs should not be forced into the planting hole, distorted, or broken during planting. After placing the plant in the hole, excavated soil is placed firmly around the root system so there is no loose soil or air pockets around the root plug. The root system must not be damaged during this operation. A small circular water-holding basin can be created around each seedling after planting to capture water or store irrigation water.

10.3.4.8 Administer Contract

The planting contract inspector must 1) schedule the shipment of seedlings from the nursery, 2) be certain that root plugs are moist and ready for planting, 3) have the right quantities of plants at each planting area, and 4) inspect the contract. In addition, if there are special planting patterns designed for the planting area, these may need to be marked on the site prior to planting.

The planting inspector must determine if the conditions are favorable for planting. Seedlings should not be planted into dry soil unless the planting spot is irrigated immediately after

__Figure 10.129 –__ Monitoring the survival and growth of nursery stock for several years after planting provides valuable information for future projects.



planting or the pot planter method is being used. Under certain circumstances, high moisture soils follow geomorphic features, such as creek or river terraces where high ground water brings moisture to the soil surface. These sites should be identified on the ground at the time of planting.

10.3.4.9 Monitor Planting Success

Valuable information can be gained by monitoring nursery stock for several years after planting. The first few months are critical because nursery plants that die immediately after outplanting indicate a problem with nursery stock quality. Plants that survive initially, but gradually lose vigor, indicate poor planting or drought conditions. Therefore, plots must be monitored during and at the end of the first year for initial survival. Subsequent checks after 3 years will give a good indication of plant growth potential (Figure 10.129). This performance information is then used to give valuable feedback to the nursery manager, who can fine-tune the target specifications for the next crop.

10.4 POST INSTALLATION CARE OF PLANT MATERIALS

The first year after plant materials are installed on a project site is typically the most critical period in a revegetation project because this is when plants become established. Applying the appropriate mitigation measures to improve the site and soil conditions prior to installation of plant materials greatly increases the chances of plant establishment. Sometimes even these measures are not enough to overcome limiting site factors. The implementation guides in this section cover several post installation measures that can be done to increase the potential of plant establishment.

Establishing plants from nursery stock is often limited by animal browsing. Section 10.4.2, Animal Protection, covers the methods available for protecting plants from different forms of animal damage. On hot, dry sites, plants need to be shaded from mid to late afternoon solar radiation. The application of shade cards, Section 10.4.3, is one method for protecting young plants from heat stresses. Moderating the climate around plants from extreme temperatures and high evapotranspiration rates is sometimes accomplished through the use of tree shelters. Section 10.4.4, Tree Shelters, outlines when these structures are used, product types, and how they are applied. Some projects require supplemental irrigation for establishing seedlings on extremely dry sites. Section 10.4.5, Irrigation, discusses two types of irrigation used in revegetation projects – deep pot irrigation and drip irrigation.

10.4.1 INTRODUCTION

The first several years after the installation of seedlings are critical for the survival of healthy nursery plants. In the western United States, nursery plants die because of animal damage, high surface temperatures, high evapotranspiration rates, lack of soil moisture, and vegetative competition. In this section, we will discuss certain steps to reduce these impacts. Where animal browsing is high, fencing, netting, and animal repellants are important to consider (See Section 10.4.2). For high surface soil temperatures shade cards can be used to protect seedlings (See Section 10.4.3). Reducing evapotranspiration rates is achieved using tree shelters (See Section 10.4.4) and shade cards. Some high visibility projects require fast growth rates and low risk in plant establishment, in which case irrigation can be considered (See Section 10.4.5). Additional measures that benefit seedling survival are covered in other sections. These include applying mulch around seedlings to conserve soil moisture and reduce vegetative competition (See Section 10.1.3), spot fertilizing (See Section 10.1.1), and applying mycorrhizal inoculum (See Section 10.1.7).

10.4.2 ANIMAL PROTECTION

Planted seedlings can be damaged by a variety of animals, including cattle, deer, elk, gophers, and voles. While some damage by animals can be expected, excessive damage should be prevented. There are a variety of methods to protect seedlings which include rigid and non-rigid netting, fencing, and animal repellents.

10.4.2.1. Netting

A common practice for protecting seedlings from browsing animals is to install a plastic netting over each seedling. The netting acts as a barrier to foraging of foliage, stems, and even root systems, without impeding plant growth. It has been used to protect seedlings from deer, elk, gophers, and other ground burrowing animals.

There are two general types of netting – rigid and non-rigid. Non-rigid netting is a soft, fine-mesh plastic material. When installed on a seedling, it fits snuggly around the foliage like a sock. The rigid netting (Figure 10.130) has larger mesh openings and holds its form when installed. Rigid netting, while typically more expensive, is usually preferred over non-rigid because it is easier to install and seedling growth inside the netting is less restricted.

Netting must be installed as soon after planting as possible to ensure immediate protection. If installation occurs after bud break, care must be taken not to break or damage the terminal leaders or buds. Rigid netting is held in place with one or two bamboo stakes woven through the netting at three places and driven into the soil at a minimum depth of 8 inches. For deer and elk protection, netting is placed so the height of the netting is several inches or more above the terminal bud. Non-rigid netting is simply placed over the foliage like a sock and

Figure 10.130 – *Rigid netting can protect seedlings from deer, elk, and gopher damage. The netting in this picture was installed 3 inches below the ground line to protect the seedling from gophers while the foliage and terminal leader is protected from deer and elk browsing.*

not secured with stakes. Rigid netting can offer some protection from gopher damage if the netting is installed more than several inches below the surface of the soil (Figure 10.130).

The effectiveness of the netting decreases as the terminal leader grows out of the rigid netting and become susceptible to browsing. At this point, the netting can be repositioned upward to protect the terminal leader, which requires annual maintenance. At some point, netting must be removed entirely to avoid restricting seedling growth and ultimately killing the seedling. Some netting has been manufactured with photodegradable material which will break down within several years, eliminating the need for removal. Nevertheless, sites that have had any type of plastic netting installed on seedlings should be visited several years after planting to determine whether the plastic netting is decomposing or needs to be removed.

10.4.2 2. Fencing

Fencing is often used to protect planted or seeded areas from wild ungulate and livestock grazing or trampling. Each group of animals requires different fencing specifications. Fence height for wild ungulates require 8 to 12 ft (Helgerson and others 1992) while fence height for livestock is 4 to 5 ft. Fences must be installed prior to seeding or planting to ensure optimal plant establishment.

Fencing entire planting or seeding areas is expensive to install and maintain. Maintenance must be given high priority because one break or opening in the fence will place the entire project at risk. It has been recommended that fences be monitored and maintained at least once a week and up to three times per week during peak browse season (Greaves and others 1978).

An alternative to fencing entire planting areas is to fence strategically located areas, such as planting islands. Fenced areas, called exclosures, range in diameter from 6 to 15 ft and are typically constructed with a 14 gauge, galvanized welded wire mesh (2- by 4-inch openings). Fence heights can be reduced around small diameter exclosures because wild ungulates are less likely to jump into small areas (Gobar 2006). Fence heights as low as 5 ft have been installed with good results (Riley 1999). In this strategy, the smaller size and greater number of exclosures reduces the risk of a failed project. After seedlings have grown high enough to withstand grazing and browsing pressures, small enclosures should be removed.

10.4.2.3. Animal Repellent

Browsing by deer and elk can be temporarily controlled by applying animal repellents to the foliage of seedlings. There are a variety of repellents on the market with varying degrees of effectiveness. Trent and others (2001) tested 20 products for effectiveness in reducing deer browse on western redcedar (*Thuja plicata*) seedlings and found that products emitting

***Figure 10.131** – Shade cards are placed on the south side of the seedling so the shadow cast by the shelter protects the lower portion of the seedling. This photo was taken two years after shade card placement.*

sulfurous odors were the most effective. These products contain active ingredients such as "putrescent whole egg solids" or "meat meal." Less effective products were those causing pain or irritation, containing active ingredients such as capsaicin, garlic, d-limonene, and thiram. Of the products tested, the least effective repellents protected seedlings for a few weeks, while the most effective protected seedlings for up to three months. Since seedlings are generally more palatable after winter dormancy, deer repellents should be applied just before bud break (Helgerson and others 1992) and at several month intervals during the active growing period as needed. Animal repellents in a hydrophilic powder formulation are reported to adhere better and last longer in climates with high rainfall than liquid forms (Helgerson and others 1992).

10.4.3 SHADE CARDS

Since high soil surface temperatures can limit seedling survival and growth, it is important that the stem of the seedling (where heat buildup occurs and causes the most damage) is shaded from the sun (Childs and Flint 1987). Seedlings can be planted next to obstructions, such as logs, to utilize the shade these structures provide. Unless the placement of obstacles is planned into the project, construction sites will usually be free of material large enough to cast shadows. An alternative, but less effective, method of creating shade is using shade cards. Shade cards are small, easy-to-install structures that shade the lower portions of the seedling from high surface soil temperatures (Figure 10.131). Tesch and Helms (1992) reviewed numerous studies that evaluated the effects of shade cards on planted seedlings and found that, while the use of shade cards can significantly improve seedling survival, they should only be considered on sites where several revegetation conditions are suboptimal, including south-facing aspects, sites with high winds, or when planting small, poor quality stock.

To be effective, shade cards should be installed in the spring after planting and before hot weather sets in. It is important to know where the shadow of the installed shade card will be cast in order to know where to place the card. The shadow must cast shade on the stem and lower portions of the seedling to protect these areas from high surface temperatures during the hottest portion of the day (Childs and Flint 1987). The length of the shadow is dependent on the longitude, date, time of day, slope angle, and height of the shade card. Improper installation of shade cards is a common mistake which typically occurs when cards are placed on the wrong side of the seedling. Card installers must be aware of the cardinal directions at all times during the day, which can be difficult on cloudy days. For this reason, contractors and inspectors should use a compass when installing cards and inspecting contracts. Another common mistake is not placing the shade card close enough to shade the base of the seedling during the hottest times of day.

Shade cards are also used to protect seedlings from strong, drying winds that create high moisture stress for establishing seedlings. Typically, shade cards are placed on the windward side of the seedling to deflect the wind. It is important to know the direction of the strongest or hottest wind in order to properly install the shade cards. For example, on a site with strong, drying winds coming up-valley in the afternoon, two shade cards would be installed at 90° angle to each other on the down-valley side to enclose the seedling.

Shade cards are made from shingles, cardboard, tarpaper, and polypropylene mesh. Selecting the appropriate shade card for your site should be based on how easy the shade card is to install, the weight, dimensions, life span, and costs. The drawbacks to the use of shade cards are the visual impact on the site and the fact that they must be removed after several years.

10.4.4 TREE SHELTERS

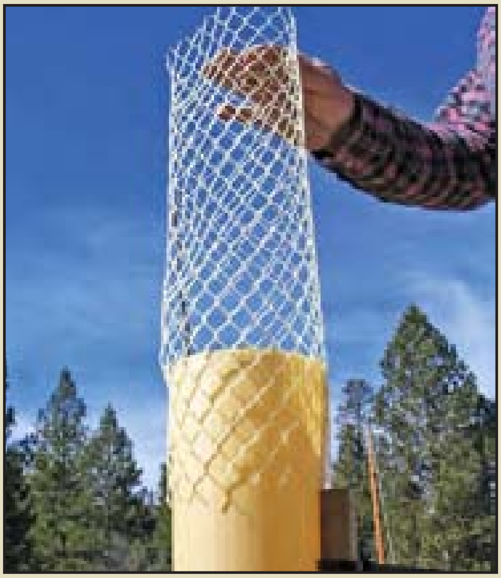
Tree shelters are translucent plastic tubes that are placed around seedlings after planting (Figure 10.132). They benefit seedling establishment by creating a favorable growing environment while shielding the seedling against animal damage. Tree shelters enhance plant growth by creating a microclimate similar to a mini-greenhouse, which has lower light intensities, higher temperatures, and higher relative humidities (Applegate and Bragg 1989; Jacobs and Steinbeck 2001). On high elevation sites, tree shelters increase above-ground temperatures and extend the growing season (Jacobs and Steinbeck 2001). Seedling survival and growth is enhanced by tree shelters on some sites because increased condensation on the inner shelter walls during the evening, drips into the soil and increases soil moisture (Bergez and Cupraz 1997). On windy sites, tree shelters protect seedlings from wind damage and blowing sands (Bainbridge 1994). In addition, tree shelters protect seedlings from large game, gophers, rabbits, voles, and grasshoppers (Tuley 1985; McCreary and Tecklin 1997; Jacobs and Steinbeck 2001).

Where to Use: Tree shelters should be considered for sites where the potential for animal damage is extreme and seedling survival and rapid seedling growth are essential. These sites include but are not limited to sites with the following characteristics:

- Gopher or vole damage,
- High elevation,
- High winds,
- Hot and dry,
- High solar intensity,
- Low water-holding capacity soils, and
- “One-shot” planting.

Figure 10.132 – *Corrugated plastic tree shelters create a microclimate around seedlings to enhance moisture and temperatures for seedling growth. In addition, they protect plants from animal browsing.*

Figure 10.133 – *Rigid tubing can be installed over the top of the tree shelter to protect seedlings from larger browsing animals.*



Drawbacks: Tree shelters are not intended for all species or site conditions. Several studies have shown that, under certain climates, seedlings grown in tree shelters are more susceptible to low temperature extremes than those grown in the open (Svihra and others 1993; Kjelgren and others 1997). These conditions occur in the late winter and early spring on some sites when warmer daily temperatures in tree shelters induce earlier bud break and stem dehardening, leaving seedlings more susceptible to cold temperatures. Air temperatures can also be colder at night in tree shelters on some sites because tree shelters can potentially trap cold air near the ground surface (Swistock and others 1999). On the opposite extreme, extremely high temperatures in the summer can be reached inside the shelters during mid-day, which might be detrimental to seedling growth. For these reasons, installing tree shelters should be done with some understanding of the effects that the shelters will have on each species to be planted and the climate of the site. Small trials, prior to installation, can point out potential problems.

In visually sensitive areas, tree shelters do not blend well with natural backgrounds. Depending on the species and the site, tree shelters might have to remain around plants for up to five years. In addition, long range planning for shelter removal is critical; without removal, the stem of the plant can be restricted.

Installation: Installing tree shelters may be done during or immediately after planting to protect seedlings from animal damage. Tree shelters are usually delivered in stacks of plastic sheets. They are assembled on site into cylinders that are placed over the seedling and held upright with a stake (Figure 10.132). The stake is driven into the soil so that the bottom of each cylinder is in direct contact with the soil surface. If burrowing animals are a problem, shelters can be installed several inches below the soil surface. This is an effective control of gophers and voles (McCreary and Tecklin 1997; Jacobs and Steinbeck 2001). Netting is sometimes placed over the opening of the shelter to prevent birds and lizards from becoming trapped (Bainbridge 1994). Rigid tubing can be placed over the top of the tree shelter to protect the emerging foliage from deer and elk browse (Figure 10.133). Tall tree shelters will require very strong stakes anchored firmly in the soil to withstand strong winds. As the shelters are installed, care must be taken to avoid skinned bark, damaged buds, or broken leaders. Where moisture is a limiting factor, weeding the vegetation from around the shelters is essential. Seedlings competing with weeds are unlikely to take advantage of the water saved by a tree shelter (Bainbridge 1994; McCreary and Tecklin 1997).

Maintenance and Removal: Installed properly, tree shelters require little maintenance. Nevertheless, sites where tree shelters are installed should be inspected annually to assess seedling conditions in the tree shelter and determine if any maintenance is needed. Since yellow jackets and other animals create homes inside tree shelters, it is wise to be cautious when conducting inspections.

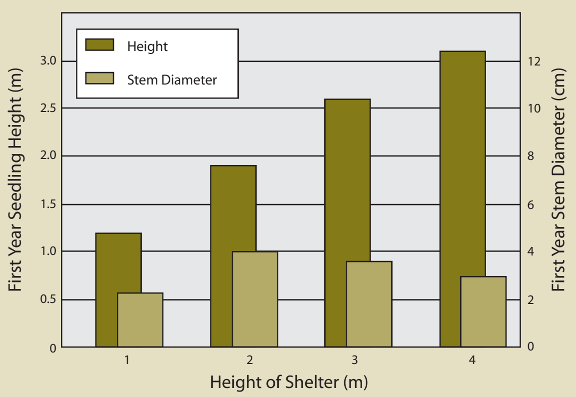


***Figure 10.134** – A study conducted with Australian redcedar* (Toona australis) *on a warm, moist site in North Queensland showed that, as taller tree shelters are used, first year shoot growth increases. Stem diameters, however, do not change (Applegate and Bragg 1989).*

Tree shelters create growing conditions that favor seedling height growth over stem diameter growth (Figure 10.134). Since tree shelters physically support the seedlings while they are growing, the seedling directs more of its energy into growing up to the light and less into the stem. Tree shelters must not be removed until a portion of the seedling crown has grown out of the shelter. If the tree shelter is removed while it is still growing inside the shelter, the seedling will not be capable of supporting itself. Once the seedling has emerged from the shelter, stem diameters will continue to increase as the foliage acclimates.

Available Products: Tree shelters are available in a variety of shapes, sizes, colors, and styles from companies that specialize in reforestation, restoration products, or grape growing.

Color. Color and translucency of the plastic are important characteristics for selecting a tree shelter. Brown-colored tree shelters greatly reduce solar radiation and, in one study on a high elevation site, was shown to drastically decrease seedling survival of Engelmann spruce (*Picea engelmannii*) (Jacobs and Steinbeck 2001). But on hot, dry sites, reduced radiation might benefit seedlings. Oak seedlings (*Quercus* spp).planted in a semi-arid environment actually performed best in short, brown-colored shelters because of reduced daily temperatures (Bellot and others 2002).

Lighter colored tree shelters allow greater solar radiation to reach the seedling, but can also heat up when they are exposed to direct sunlight. Highly translucent tree shelters should be considered where light is limiting. On the other hand, low translucent shelters might be more appropriate for sites where solar radiation and mid-day temperatures are high in order to reduce the potential for overheating.

Material. Tree shelters are made from translucent plastic for light transmission built with different degrees of sturdiness. Corrugated tree shelters are the sturdiest and are used on sites with strong winds. Corrugated materials are also used in the taller tree shelters for added support (Figure 10.132), while thin plastic can be used in shorter shelters. Tree shelters are typically designed to degrade in five years, but in many cases they do not. Many shelters can therefore be reused, which will reduce project costs.

Ventilation. Without ventilation, tree shelters will build up heat on warm days, especially if they are in direct solar radiation. Maximum daily summer temperature in shelters can be 8 to 16 °C (15 to 30 °F) higher than ambient air temperatures (Steinfeld 2005). Extreme temperatures can be reached on days where ambient air temperatures exceed 38 °C (100 °F). For these sites, shelters with some form of ventilation, such as holes, should be used. Ventilated tree shelters have been shown to reduce maximum daily shelter temperatures by 3 °C (5 °F) (Swistock and others 1999). Where ventilation is needed, taller shelters will require more ventilation than shorter shelters.

A ventilated tree shelter may restrict CO_2 in the area around the seedlings, which would be a further consideration for ventilation. Some studies have shown that CO_2 is very low in shelters (Dupraz and Bergez 1997). However, other studies that have shown higher levels of CO_2 within shelters than outside (Frearson and Weiss 1987).

Size. Selecting the size of the shelter should be based on the anticipated growth rates of the species planted and the anticipated animal damage. Shelter heights range from 1 to 9 ft, and

***Figure 10.135 –** Small tree shelters can be placed around germinating seeds to enhance germination and early seedling establishment, as shown in this picture of an establishing California black oak* (Quercus kelloggii) *seedling in a tree shelter made out of x-ray film.*

diameters up to 6 inches. To obtain the greatest benefit from tree shelters, the shelter height should not exceed the maximum seedling growth in the first year. Fast-growing species should have tall shelters; shorter shelters should be used for slow-growing species. Ideally, the shelter height should be greater than the browsing level of the foraging animal. For instance, tree shelter heights in deer browse areas should be at least 4 ft tall so that new seedling growth from the top of the tube is not severely browsed back. Extending the protection of the tree shelter can be done by using a rigid netting placed over the top of the shelter. Large shelters can be cut into any height or diameter needed for the project. Very small shelters (less than 6 inches tall) can be used around germinating seeds to protect them from small animals and create a micro-climate for germination (Figure 10.135).

Costs: Tree shelters can be an expensive addition to the revegetation project. The high costs to purchase, assemble, install, maintain, and remove shelters should be considered against the benefit of increase survival and growth. On projects where smaller, less expensive seedlings are being planted, the cost savings from not planting larger stock can offset the installation of tree shelters. Assuming that tree shelters increase seedling survival, fewer seedlings would need to be planted, and these savings could offset the costs of installing tree shelters. Where quick establishment of vegetation is the objective, the use of tree shelters should be considered.

10.4.5 IRRIGATION

There is a wide range of irrigation methods and techniques available to the revegetation specialist, ranging from simple to elaborate, and modestly priced to costly. Since irrigation is often a very expensive revegetation strategy for most projects, the decision to irrigate, and subsequently the selection and design, must be integrated into the objectives of the road project during the planning stages. The most common reason for irrigating in the western United States is to aid in seedling survival during the first several growing seasons. Those sites that have low soil water-holding capacities, high evapotranspiration rates, or low summer rainfall meet these criteria. Irrigation is also used when the project objectives call for a quick establishment of vegetation for visual screening, erosion control, or slope stabilization. Wildland irrigation is almost always a temporary measure, spanning a maximum of three years. Therefore, elaborate or expensive irrigation systems are not often the best choice for these situations. Low-tech systems, requiring minimal maintenance, tend to be more appropriate for wildland restoration.

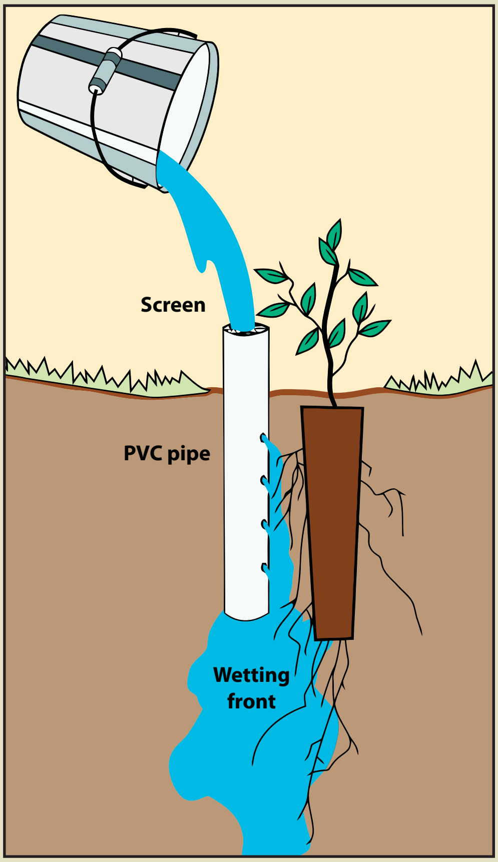
The challenge in wildland irrigation is the timing and placement of water in the soil. An irrigation system that delivers water when the plant is less likely to need it is wasteful and can be detrimental to the seedling. A system or schedule that applies water when the plant requires it for survival or growth is most cost effective and beneficial for seedling survival and growth.

Developing irrigation schedules based on plant needs is an essential part of using irrigation for establishing plants, and those needs change based on the species being established, nursery stocktype, soils, and climate.

Placing the water in the soil profile where it can be directly accessed by much of the root system is critical for efficient use of an irrigation system. Some irrigation systems moisten more of the soil profile than will be accessible by the establishing root system, and water is consequently wasted. Other ineffective systems barely wet the soil surface, leaving the applicator satisfied, but the roots without water. The objective of an efficient and effective irrigation system in wildland settings is to deliver only the amount of water needed, when and where it is needed for seedling survival and growth.

Tree and shrub seedlings survive by growing roots down into the soil profile, accessing moisture at deeper portions of the soil profile than annual grasses and forbs. Deep placement of water for these species is far more important than surface soil moisture. Yet many irrigation systems, such as drip, basin, and overhead sprinklers, deliver water through the surface, wetting soil where it is not needed, and encouraging weeds and other competitive plants to establish and thrive. Furthermore, surface irrigation does not always assure moisture will be evenly delivered to the deeper portions of the soil where the roots of trees and shrubs are growing. Soil structure and texture affect the wetting-front patterns of surface-applied irrigation water. If the soil is compacted, the amount of water that is delivered to the lower rooting zone can be reduced. A better method of water delivery to the root zone of trees and shrubs is to bypass the surface of the soil completely.

***Figure 10.136 –** Deep pot irrigation uses an open-ended PVC pipe placed next to a planted seedling. Small holes (1 mm) are drilled 2 to 3 inches down the pipe and positioned toward the root system. A screen is placed over the top of the pipe to keep animals out. The size of the pipe and placement is designed to deliver the appropriate amount of water to actively growing roots (modified after Bainbridge 2006b).*



10.4.5.1 Deep Pot Irrigation

There are several irrigation methods developed for arid land revegetation that bypass the soil surface and deliver water directly to the root zone. These systems include deep pot, porous hose, and wick irrigation methods (Bainbridge 2006a). Because these systems deliver water directly to the soil profile where roots are actively growing, far less water is required. Deep pot irrigation (Figure 10.136) appears to be the most effective and practical method for irrigating planted seedlings in arid environments (Bainbridge 2006b). This system has been found to be three times more effective at increasing seedling survival than surface irrigation using the same amount of water (Bainbridge and others 2001).

Deep pot irrigation delivers water to the root system through a pipe positioned next to the seedling (Figure 10.136). The pipe is either filled periodically by hand or through an installed drip irrigation system. The soil is moistened as water drains through both the bottom of the PVC pipe and the holes drilled in the sides. The amount of water delivered to the soil depends on the size of the pipe and how much water is applied. Deep

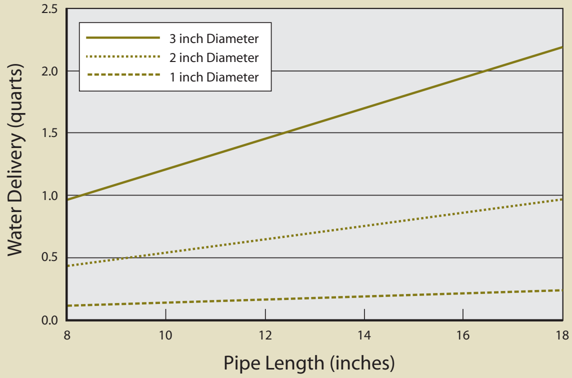


***Figure 10.137** – The maximum amount of water that can be delivered to a root system in a single irrigation (y axis) is determined by the pipe length (x axis) and the diameter of the deep pot (lines). For example, a 14-inch pipe with a 1-inch diameter will hold approximately 0.15 quarts of water; a 2-inch diameter pipe will hold 0.75 quarts; a 3-inch diameter pipe will hold 1.7 quarts of water.*

pot irrigation pipes are typically made from PVC pipes, though most pipe or tubing material can be used. Pipe diameters range from 0.5 to 3 inches. Pipe lengths range from 8 to 18 inches, depending on the stocktype and water volume to be delivered. A seedling with a short root plug will require a shorter pipe, whereas a longer root plug will require a longer pipe. The bottom of the pipe should be positioned no deeper than the length of the root plug so the wetting front moves around the bottom and lower portions of the plug where it can be accessed by new, advancing roots. The top of the pipe is screened to prevent animal entry and is placed several inches above the level of the soil.

The diameter of the pipe will determine the quantity of water that can be delivered at any one irrigation (Figure 10.137). Given the same pipe lengths, a 2 inch diameter pipe holds 4 times the amount of water as a 1 inch pipe, and a 3 inch diameter pipe holds 8 times the amount of water. Since filling pipes is expensive, determining the proper diameter is important. Oversized pipes will deliver a wetting front that extends beyond where it can be accessed by the root system, and water will be wasted. Pipes that are too small will not fully wet the area around the advancing rooting zone, requiring more frequent irrigations. Pipe size and irrigation frequencies depend on:

Soil Type – Sandy or rocky soils have low water-holding capacities, causing wetting fronts to travel deeper and in a narrower band. Less water but more frequent irrigations are needed in these soils. Pipes must be placed closer to the root plug to ensure the wetting front reaches the root system. Finer textured soils, such as loams and clays, have a higher water-holding capacity and wider wetting fronts. More water can be applied in these soil types and at less frequent intervals than sandy soils.

Stocktype – Large stocktypes have greater root volumes and greater above-ground vegetation to support than smaller stocktypes, and therefore require more irrigation water. However, smaller stocktypes might require more frequent irrigation.

Seedling Quality – Healthy seedlings grow new roots quickly and can access deeper soil moisture. Poor quality seedlings are slow to initiate roots and therefore must be irrigated more frequently.

Competing Vegetation – Where undesirable vegetation is growing near planted seedlings, soil moisture is depleted sooner, requiring more frequent irrigations than if seedlings were free from competing vegetation.

Species – Every species has unique rooting patterns, growth rates, and water needs. Those that grow roots quickly and have a higher rate of water withdrawal require larger, deeper pipes and more frequent irrigations. These species include many of the fast growing riparian species such as cottonwoods, willows, and maples. For more information, contact the nursery manager growing the species of interest. They are very familiar with root growth and water needs by species.

The volume of the pipes and frequency of irrigations will determine the type of water delivery system to use. Sites that need frequent irrigations and high volumes of water per plant might require water delivery through a drip system (See Section 10.4.5.2). For most projects, however, pipes can be economically watered by hand using backpack spray equipment or fire bladder bags. Bladder bags hold approximately 5 gallons of water and can be filled from water trucks or large water containers positioned in pickup beds. Assuming that an irrigator can carry 20 quarts of water at a time (5 gallons) and each plant in the project requires a quart of water, the applicator could irrigate 20 seedlings before returning for more water. If less water is required, more plants could be irrigated before refilling is necessary.

Deep pot irrigation allows for the introduction of soluble fertilizers (See Section 10.1.1) and mycorrhizal fungi inoculum (See Section 10.1.7) if seedlings require these treatments. Since soluble fertilizers are delivered directly to the roots, bypassing the soil surface, weeds are not encouraged to grow. Care must be taken when determining fertilizer rates to avoid increasing soluble salts above levels that are toxic for root growth. Salt levels and pH of the irrigation water must be monitored to assure that salts do not exceed toxicity levels for plant growth (See Section 5.5.5, pH and Salts).

Determining when to irrigate can be based on the moisture stress status of the plant. An accurate method for determining plant moisture stress (PMS) is using a pressure chamber (Inset 10.23). This equipment reads plant stress (in negative bars) at the time of the readings. PMS readings should be made in the early morning, prior to sunrise, when diurnal PMS is at its lowest. Five seedlings should be collected in one area and averaged per site. If pre-dawn PMS readings are less than -15 bars, seedlings are under high moisture stress and must be irrigated soon to keep the seedlings from dying. If the objective of irrigation is for fast seedling growth, then PMS during the plant growth (spring and fall) must be kept above -5 bars. PMS equipment is expensive to purchase. However, many Forest Service district offices use and maintain this equipment.

10.4.5.2 Drip Irrigation

Drip (or low pressure) irrigation is generally a temporary measure to help establish roadside plantings. It is typically used for one or two seasons to establish nursery-grown plants and then removed. Setting up drip irrigation might be considered extravagant. For projects where there is no tolerance for seedling failure, this can be a viable, economical alternative (Bean and others 2004).

Some advantages of using drip systems for roadsides are water efficiency, system flexibility, portability, and ease of application of soluble fertilizers. The main disadvantage is the high maintenance required to keep the system operational. Drip systems are composed of numerous points where failures can occur: storage tanks, burst end clamps, connectors, emitters, hundreds of feet of pipe and drip irrigation tubing. For this reason, the system must be inspected and maintained regularly during the summer to assure that all seedlings are being properly irrigated. This involves inspecting all emitters, pipes, tubing, and tanks. Emitters clog with sediment and insects (Bainbridge 2006c); animals gnaw through tubing when it is above ground; and plastic water tanks make great shooting targets. These damages to the system must be repaired before each irrigation cycle. Another disadvantage is that, on hilly sites, the system must be designed to maintain the correct pressure to each emitter.

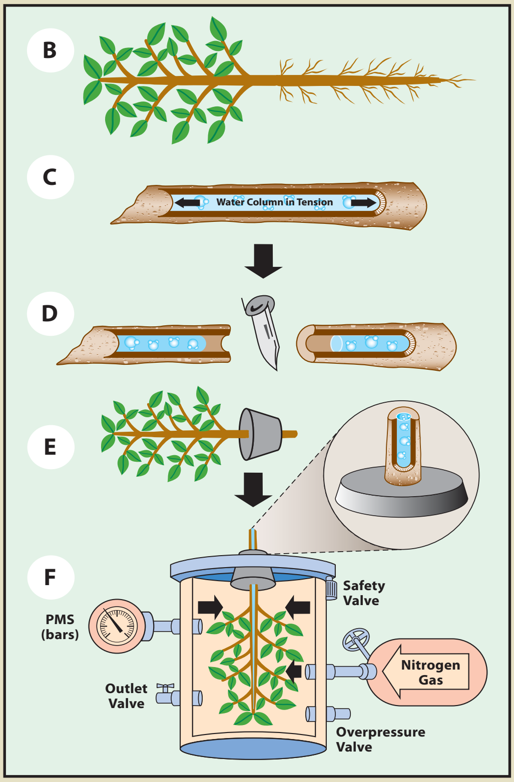
In its simplest form, the drip irrigation system consists of: 1) a water source, 2) mainline and side lateral pipes, and 3) drip pipes and emitters. The system is under pressure during irrigation, which moves water from the water source, through the mainline and side laterals, to the emitters where seedlings are watered. The objective is to deliver equal amounts of water to each seedling. This is not a problem when the system is laid out on flat ground and pressures at any point in the system are equal, but flat terrain is seldom found on highway projects. On projects that have any slope gradients, there will be changes in pressure depending on the elevation of the emitters. The pressure change occurs at a rate of 1 lb/in^2 (PSI) per 2.31 ft elevation drop. This means that an emitter at an elevation that is 46 ft lower than the water source will have a PSI of 20 (46/2.31 = 20), while an emitter at 92 ft lower than the water source will have a PSI of 40 (92/2.31 = 40). Unless pressure-regulating techniques are used to reduce the pressure to the lower elevation emitters, the amount of water delivered to those emitters will be approximately twice that of the upper elevation emitters. Compensating for pressure changes is critical for delivering equal amounts of water to each seedling. Systems that do not compensate will have seedlings that receive too much water, while others will not receive enough during an irrigation cycle.

Water Source – The water source constitutes the beginning point of the drip system. It is typically the most uphill point because it must feed every emitter below. Water is typically trucked to the site and pumped directly into the mainline, or stored in temporary, portable storage tanks (Figure 10.138). Water trucks range in capacity from 1,000 to 2,500 gallons. If there is a location for a portable water storage tank above the planting area, gravity feed can be used

Inset 10.23 – Measuring Plant Moisture Stress
(modified from McDonald 1984)

Measuring plant moisture stress (PMS) is an accurate method to help determine the water needs and status of a plant. When a seedling (A) is under moisture stress, it is pulling water from the soil through the stem. The water in the stem is under tension, much like a rubber band that is being stretched (B). When a small branch is cut, the tension in the stem is released and the water shrinks back from the cut surface (C). The further back the water shrinks, the more moisture stress the plant is under. The cut end of the stem is placed through a small hole in a stopper, with the end protruding from the lid (D). The foliage is placed in the steel chamber and tightened so it is airtight (E). Nitrogen gas is slowly applied into the chamber, exerting pressure through the stomata and pushing water through the stem toward the cut end. When the water just begins to emerge from the cut end, a pressure reading is made. This is the amount of suction or stress that the seedling is under at the time the sample was collected. Since PMS varies throughout a 24-hour period, seedling samples must be taken in the pre-dawn for consistency and comparison purposes.

PMS readings can be used to determine when to irrigate seedlings. If pre-dawn PMS readings are greater than -15 bars, seedlings are under high moisture stress and must be irrigated soon to keep the seedlings healthy. If the objective of irrigation is for fast seedling growth, then PMS during the plant growth (spring and fall) must be kept below -5 bars. PMS equipment is expensive to purchase; however, many Forest Service district offices use and maintain this equipment.

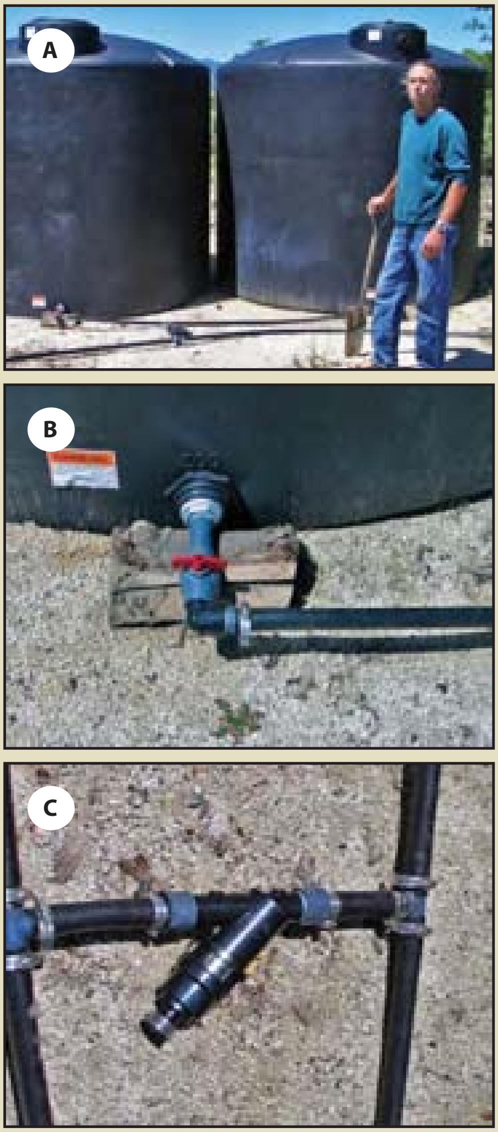


to pressurize the system. Operational water pressure for a drip system ranges from 20 to 40 PSI. To achieve a minimum pressure of 20 PSI with a gravity feed system requires a 46 ft elevation drop from the storage tank to the first line of emitters (20 * 2.31 = 46). If this drop does not exist, then a pump will be needed to augment the pressure.

Components of a temporary water tank system include filters, on-off valve, backflow, and a pressure-reducing valve (if the water source pressure is greater than 40 PSI) (Stryker 2001). When planning water storage, ease of access is an important consideration. Sometimes water will need to be pumped a substantial distance to a water storage tank. In other cases, more than one tank will be required to reach all planting areas in complex terrain. Water from unknown sources should be sent to a qualified lab and analyzed for contaminants and impurities (Zoldoske 1998). Chances are that most water sources will have impurities that will clog very small drip emitter openings. Installing a 100 (150 micron) to 150 (100 micron) mesh filter is recommended (Stryker 2001).

Mainline and Laterals – The mainline delivers water from the water source to the lateral pipes. The layout of the mainline and laterals can compensate for pressure changes associated with hilly terrain. A series of parallel lateral lines can be laid out perpendicular to the slope gradient. Since each line is on the contour, there is no pressure difference between emitters within a line. Between lateral lines, however, there is change in pressure based on 1 PSI per 2.31 ft elevation drop. Placing a pressure regulator at the connection between the mainline and each lateral line can compensate for the pressure increase with elevation drop.

Figure 10.138 – *Large holding tanks are used for temporary drip irrigation systems (A). A simple on/off valve controls water to the gravity-feed system (B). Pressure release valves (C) are used to control water pressure on hilly sites.*



The drip tubing diameter determines the volume of water that can be carried in the lateral lines and the rate it will be delivered based on friction losses. A two inch pipe, for instance, carries four times as much water as a one inch pipe, but the costs are correspondingly much higher. For long stretches, increased frictional losses inside narrow diameter pipes can cause inadequate water coverage. Increasing water pressures or increasing pipe diameters can compensate for this.

The carrying capacity is the amount of water that specific tubing can deliver under a specific line pressure. For example, 0.75-inch tubing has a carrying capacity of approximately 160 gallons per hour at a line pressure of 20 PSI, whereas 1-inch pipe has a carrying capacity of 370 gallons per hour at the same pressure. Charts are available that compare various tubing diameters, emitter outputs, and system pressures for determining the length of tubing. These charts must be referenced when designing an efficient drip system.

Emitters – From the laterals, water flows through a smaller diameter pipe to the emitter, which meters out water directly to the base of each plant. Emitters apply water to the soil surface without wasting water on the surrounding area, thus discouraging non-target species. When emitters are placed in a deep pot irrigation system, water efficiency is increased further because water is delivered directly to the roots. There are many types of emitters, but pressure compensating emitters work well on hilly topography because they are designed to discharge water at uniform rates under a range of water pressures. With pressure compensating emitters, a system at 15 PSI would have the same emitter flow rate as a system at 45 PSI (Stryker 2001). These emitters are two to three times more expensive than non-compensating emitters.

Emitters come in a range of flow rates, with the most common rates of 2 liters/hour and 4 liters/hour. Choosing the flow rate for the emitters should be based on soil texture, water requirements of the plants, water delivery capabilities of a system, and budget. Most designers agree that placing two emitters at each plant is better than one emitter with twice the output, because the water distribution area will more closely match the rooting profile of the plant. Two emitters also offer backup should one of the emitters become clogged.

A good grasp of the soil drainage and water storage characteristics is necessary in choosing emitter capacity and duration of irrigations. Well-drained soils (e.g., sandy texture or high coarse fragments) require emitters with higher flow rates, but shorter irrigation time. On the other hand, poorly drained soils (higher in clays, or compacted) require lower output emitters and longer irrigations. Size of planting stock will influence the number of emitters and flow rates; the larger the planting stock, the longer the irrigation cycles and more output emitters are needed.

There are a limited number of emitters that can be installed on any one lateral line. For example, 0.75-inch pipe or tubing delivers approximately 160 gallons per hour, the number of emitters that can be installed on the line will vary by emitter output rates. Installing 0.5 gallon/hour emitters allows approximately 300 emitters (600/2 = 300) on the line. If two emitters were placed by each plant, 150 plants could be watered on a line. If the emitters were rated at 1.0 gallon/hour, then 75 plants could be watered.

Installation – The installation of a drip system involves placing pipe and inserting emitters. Tubing comes in rolls and is easiest to lay out like a wheel to keep kinks from developing in the line. Lateral tubing should be placed upslope from the plant, which will act like a stake should the tubing move downslope. Tubing migrates until it has been used for a while and may require periodic staking. When the main line and laterals are in their general locations, the system is filled with water to flush the pipes clean. The ends are clamped or plugged and then filled again. This will reveal whether there are any leaks or problems to fix before installing the tubing to the emitters. A pressure gauge should be used at this time to take readings across long runs within or between lateral lines to check consistency of pressures. If there are problems, they should be corrected at this time. Puncturing tubing for emitters can be done when the system is charged with water, so that adequate emitter flows and problems are seen immediately. Some designers choose to bury emitters below the soil surface to reduce surface evaporation. Losing visual inspection, however, usually outweighs the benefits of this strategy (Zoldoske 1998).

Operation – Prior to operating the drip system, filters must be cleaned. Check salt levels and pH of the irrigation water using a pH/conductivity meter to assure that salts do not exceed toxicity levels for plant growth (See Section 5.5.5, pH and Salts). Once these measures have been taken, the system can be opened and lines and emitters inspected. If emitters need cleaning, repair, or repositioning, it is done at this time. Tools and spare parts for the system are brought along and used where needed. Determining when to irrigate should be determined through PMS monitoring (Inset 10.23). Determining the duration of the irrigation cycle can be done once or twice during the growing season through a visual inspection soil profiles dug below several emitters. Observing the wetting front should be done several hours after the system has been shut off because the wetting front will have stabilized at that time.