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Chapter

12

Seedbed Preparation and Seeding Practices

Selection and Use of Adapted Species

Selection and use of seeds of different species must be carefully considered in range and wildland improvement projects. The selection of species to be planted in any restoration program usually takes place after the decision has been made to restore or rehabilitate an area, and the objectives of the project have been determined. However, availability of seed and planting stock can delay and alter seeding programs. Seeding and planting involves an introduction of seeds and plants to a site that alters existing plant communities and influences successional processes. Most seeding projects are conducted only once, and the plant communities that ultimately develop are dependent upon the initial success of the plantings. In contrast to natural seedings that normally produce only a few new seedlings each year and may or may not alter plant composition, artificial seedings, if successful, create a dramatic and immediate change in community composition.

Figure 1—Planting adapted and compatible species in mixtures is essential in any restoration project.

Successful site improvement projects are based on the selection of adapted plant materials (Stevens 1981). There is no substitute (manipulation, management) for proper species selection (fig. 1). The factor that most often leads to project failure is the use of unadapted species. Seeded species must be able to establish and maintain themselves, whether growing alone or in mixtures with native or introduced species, often under various management systems. Some primary factors that influence species establishment are: (1) germination attributes, (2) initial establishment traits, (3) growth rates, (4) compatibility, (5) seedling tolerances, (6) persistence, and (7) grazing impacts. These and other characteristics are ranked by species in tables found in chapter 18. Some species are very site specific, whereas many others have a wide range of adaptation (Ferguson 1983; Hassell and others 1983). Following proper selection, seeds and plants must be planted using techniques and practices that provide them every possible advantage to establish. New plantings should be protected to insure perpetuation of the developing community.

Guides to Species and Ecotype Selection

Numerous factors can be used to identify species that are adapted to a planting site. Native species are normally reintroduced in many plantings. If native species have been eliminated and sites are infested with weeds, it may be difficult to determine the most adapted species to seed. If seedings are designed to alter or change the composition of the existing plant communities, the selection process can become more complex. Following are a number of guides that can be used in selecting adapted species.

Species Compatibility and Planting Objectives

Introduced grasses, including crested wheatgrass, pubescent wheatgrass, intermediate wheatgrass, smooth brome, orchardgrass, Kentucky bluegrass, and Russian wildrye, have been able to withstand adverse climatic conditions, fires, and severe grazing, and yet provide excellent forage (Cook 1966; Plummer and others 1968; Ross and others 1966). Plantings of crested wheatgrass have remained productive for over 45 years on foothill ranges in Utah (Vallentine 1989). Hard fescue, pubescent wheatgrass, and timothy are also adapted to many sites. The excellent survival, forage attributes, and ground cover values of these and other introductions have prompted their use.

This universal use of introduced perennial grasses for most range, watershed, and wildland seedings has created some serious problems (Bentley 1967). The establishment and persistence attributes of many introduced grasses have resulted in the elimination and decrease of desirable native species. Crested wheatgrass and pubescent wheatgrass formed almost closed communities 6 years after seeding on Utah foothill ranges (Cook 1966). Intermediate wheatgrass establishes more slowly, but is able to restrict growth of oakbrush and maintain nearly complete dominance of the understory (Plummer and Stewart 1944; Plummer and others 1968). Smooth brome slowly increases in dominance, and forms nearly a complete sod on many ranges, restricting native grasses and broadleaf herbs. Plantings of crested wheatgrass have slowly gained dominance in many pinyon-juniper seedings, restricting the recovery of natives (Davis 1987; Stevens 1987b; Walker and others 1995). Monsen and Shaw (1983c) reported that both intermediate and crested wheatgrass seeded as an understory with antelope bitterbrush prevented natural recruitment of shrub seedlings.

Davis (1987) found no negative seedling establishment interactions when crested, intermediate and tall wheatgrasses, smooth brome, orchardgrass, Russian wildrye, sainfoin, hard fescue, cicer milkvetch, alfalfa, yellow sweetclover, and small burnet were seeded together on a pinyon-juniper site in Utah. This study indicates these species, all introductions, are adapted to similar environments and are compatible as seedlings. However, Stevens (1987b), and Walker and others (1994), reported that where similar species were seeded on a central Utah pinyon-juniper site the cover of native perennial grasses decreased from 50 percent to about 30 percent as the introduced species attained maturity.

Incompatibility of introduced perennial grasses with native species, particularly shrubs and broadleaf herbs, reduces the desirability of seeding these grasses as a principal portion of a seed mixture if restoration of native communities is a goal. Where shrubs and other natives are desired, the use of introductions must be carefully regulated. Although introductions have excellent traits, they should be used for special situations. Studies currently in progress indicate that seeding introduced grasses at low rates may enhance the recovery and presence of native species (Davis 1987). Most long-term ecological studies, however, indicate that many introductions slowly gain dominance, and low seeding rates simply tend to delay the process.

Various introduced grasses are currently the most useful species for controlling weeds that infest and occupy extensive rangelands (Plummer and others 1970b; Vallentine 1989; Young and others 1984c). Introduced perennial grasses are considered better able to control cheatgrass, medusahead, halogeton, and many summer annual weeds than releases or wildland collections of most native species currently being planted. Native species and undisturbed communities can control weeds, but various introductions have been most successful when seeded on weed infested sites. Until the problems associated with weeds can be better addressed, and the availability of adapted native plant materials increases, the use of some introduced grasses will probably be relied upon.

Few native species have been developed for seeding most western rangelands, particularly the arid regions occupied by salt desert shrub communities. Consequently, introduced grasses have dominated the seed mixtures of many range and wildland rehabilitation programs. Many important shrublands and herblands have been converted to introduced grass-dominated communities. Some seedings have been justified because of the lack of native seed (McKell 1975), and problems associated with the establishment of natives (Vallentine 1989). In many situations these problems have been corrected. The use of appropriate native species can be attained through better planning, buying, and stockpiling of seeds.

Species that are seeded together must be compatible as young, developing plants or certain individuals will succeed and others will fail (Samuel and DePuit 1987). The amount of seed sown will affect the degree of competition, and the number and composition of seedlings that survive. Seedlings of some native broadleaf herbs and shrubs are less aggressive and succumb to competition from more rapidly developing species (Hubbard 1957; Stevens and others 1985c). Not all native species are slow growing, and many can be used as rapidly developing plants. Seeding heavy rates of the slower developing species will not offset losses from competition. Seeding slower growing species in rows separate from fast-growing herbs will result in the most favorable stands.

Drill seeding causes species in a mixture to be placed in potentially competitive situations. Seeds in a mixture that are broadcast planted are not placed in as close contact with each other as occurs with drilling, and are usually less likely to succumb to competition.

The species used must also be compatible with each other and with existing species that occur on the planting site. Few plantings are conducted on areas void of other plants. It is important to recognize that existing species can help as well as suppress new seedlings. In many situations, the presence of overstory plants improves seedbed conditions, entraps soil moisture, and protects seedlings from frost (fig. 2). Existing stands of Gambel oak, quaking aspen, antelope bitterbrush, and numerous other species enhance the establishment of understory seeded species unless the density of the overstory is excessive.

Many species improve soil fertility by fixation of nitrogen, and other species benefit by this association. Both legumes and nonleguminous species are able to increase soil nitrogen, and can be used to improve vigor and growth of associated plants. In some situations, various nonnitrogen-fixing species appear to enhance the growth of associated plants. Plants of Utah sweetvetch and Sandberg bluegrass are often seeded with other species because they appear to improve stand density of associated species.

Seeding a compatible mixture is often necessary to moderate seedbed conditions, and aid in the establishment of species that otherwise may not be able to establish alone. Many large, expansive burns in semiarid ranges are subjected to winds that dry the seedbed and remove snowcover. Big sagebrush and other small-seeded species do not establish very well on dry, barren surfaces. To establish these species, it is often necessary to establish a cover or nurse crop.

Figure 2—The presence of overstory plants can improve the establishment of seedlings.

Plant Community Indicators

Most areas selected for restoration or rehabilitation have been seriously altered, and usually support only remnant numbers of native species (fig. 3). Weeds have often invaded, and dominate the areas. Less disturbed and comparable areas usually exist nearby and can be inventoried to determine the original composition of the native communities. Remnant plants are important indices to use in determining the native vegetation. Considerable information is available to assist in classification of seral status, habitat types, and disturbed areas (Blaisdell and others 1982; Daubenmire 1970; Franklin and Dyrness 1969; Hironaka and others 1979).

The presence of remnant native species can be used to identify the major plant associations that once were present. The occurrence of less abundant species cannot always be determined by the presence of one or two remnant species, but the principal plant associations can be identified. Major plant communities that occur in the Intermountain Region are described in chapter 2. Species adapted to these communities are listed with guides for seeding mixtures.

Plants that have been successfully used in range and wildlife habitat rehabilitation programs have been chronicled for most major plant communities that occur in the West (Hafenrichter and others 1968; Horton 1989; Plummer and others 1968; Sampson and Jespersen 1963; Schopmeyer 1974b; Thornburg 1982). Most native plant communities have been classified and grouped with specific soil types, climatic conditions, and aspect. The classification system developed by Hironaka and others (1979) identifies site differences and relationships of different plant types that occur within the big sagebrush communities. This and other classification systems can be used to determine the potential of individual sites to support different plant species. The presence and distribution of different plant communities that occur throughout a proposed project area can be mapped and used to develop species mixtures.

Some severely disturbed sites may not be capable of supporting the original native species, and substitute species may be needed.

Figure 3—Native species recovering with proper management and lack of competition from neighboring species.

Climatic Conditions as a Guide

The amount of precipitation an area receives, and the season or periods when moisture is available, influence seed germination, seedling establishment, and persistence (Frasier and others 1987; Jordan 1983). Seasonal and annual precipitation are very unpredictable in arid regions, and planting sites may not receive sufficient moisture to facilitate seedling establishment every year (Bleak and others 1965). Once established, plants can usually persist during dry years, but reproduction is often delayed until periods of favorable moisture. Attempting to foretell years when artificial revegetation will be successful is quite difficult.

Sites receiving in excess of 11 inches (280 mm) of annual precipitation can be successfully planted in most years. Many sites in the 9 to 10 inch (230 to 250 mm) zone are seeded, but success is less likely (Cook 1966; Plummer and others 1968; Reynolds and Martin 1968).

Many introduced grasses have been used in rehabilitation projects because of their establishment attributes. Most are able to establish under dry, unfavorable climatic conditions, and are well adapted to a broad range of sites (Hughes and others 1962). Standard crested and fairway crested wheatgrass have been the most reliable species to establish on sites receiving 8 to 10 inches (200 to 300 mm) of moisture (Hull and Klomp 1966; Shown and others 1969). Consequently, introductions have gained considerable popularity, and frequently are relied upon when planting droughty sites.

Selection and breeding programs continue to provide native and introduced species with improved establishment traits. For example, improvements in seedling vigor of Russian wildrye and forage kochia have been reported by Asay and others (1985), McArthur and others (1990a), and Monsen and Turnipseed (1990). Additionally, selections of Sandberg bluegrass, Indian ricegrass, bottlebrush squirreltail, and Lewis flax with excellent establishment attributes have also been developed and can better establish under arid situations. Erratic stands of some native species often develop partly because of poor seed quality and germination characteristics. However, improvements in seed collection, cleaning, and storage now provide a greater number of native species adapted to arid sites.

It is not advisable to use species or ecotypes on sites that are more arid than the collection site from which the seed was obtained. Ecotypes of antelope bitterbrush, fourwing saltbush, and many other species, have failed when seeded on sites that are more arid than the native collection location (fig. 4). Although some ecotypes have become established, they will most likely succumb to adverse climatic conditions. Moving ecotypes of fourwing saltbush, Indian ricegrass, and gooseberryleaf globemallow from warmer climates to more frigid environments has not been successful. In most cases, movement of plant materials from southern desert communities to northern regions is not advised. Some exceptions do occur, as a few southern collections of winterfat, desert bitterbrush, Nevada ephedra, and Apache plume have persisted following establishment in colder northern environments.

Many rangelands receiving less than 8 to 10 inches (200 to 250 mm) of annual rainfall are infested with cheatgrass and other weeds. Various native and introduced species have been seeded in an attempt to control the weeds. Selections of big sagebrush, rubber rabbitbrush, bottlebrush squirreltail, western wheatgrass, and other species have been seeded to control weeds and initiate successional changes in the plant community (Romo and Eddleman 1988; Young and Evans 1986a). In some situations the ecotypes that were seeded exhibit aggressive establishment capabilities, but are not fully adapted to the arid sites. They may establish well, but fail to reproduce and ultimately succumb. Considerable efforts have been made to eliminate weeds and create favorable seedbeds in arid regions to aid seedling establishment (Ogden and Matthews 1959). These practices increase planting success, but do not ensure survival of the planted species. The serious infestation of annual weeds on arid rangelands continues to promote seeding of marginally adapted species and ecotypes. This situation will likely continue. However, it is inadvisable to use marginally adapted species or ecotypes in any area.

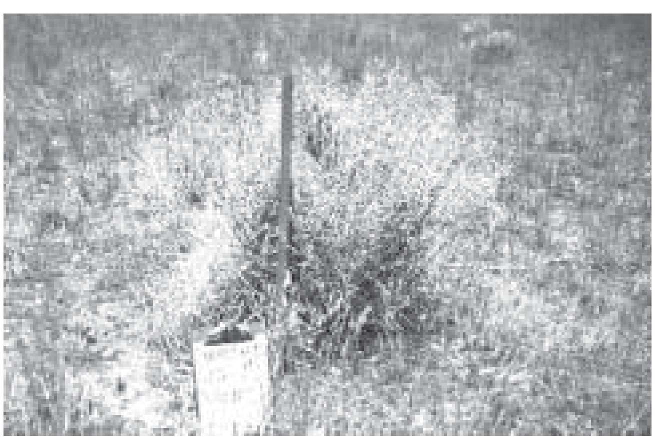

Figure 4—Death of maladapted New Mexico fourwing saltbush seeded in southern Idaho.

Soils and Parent Materials as a Guide

In general, planting sites consist of a mosaic of variable soil types that support an array of plant communities. Plants that are adapted to the different soil types and physical conditions should be sown. Seeding species mixtures has been the most practical approach to establish diverse communities (fig. 1).

Both native and introduced species have evolved on specific soils. Some ecotypes are not adapted to a wide range of soil conditions. When using native species, it is advisable to obtain seed from soils similar to the planting location. For example, antelope bitterbrush collections grown on acidic soils in central Idaho are not adapted to the basic soils of the Great Basin (Plummer and others 1968). Selections of fourwing saltbush, Indian ricegrass, Russian wildrye, and alfalfa have also been reported to differ in adaptability to soil conditions (Hassell and Baker 1985; Heinrichs 1963; Lawrence 1979; Stutz 1983). Nearly all native species consist of an assembly of different populations that have evolved under different environmental conditions. Certain ecotypes will grow over a wide range of sites. However, the range of adaptability of most native species has not been well documented. Consequently, it is advisable to plant species and sources on sites similar to their origin. It is particularly important to use plant materials acquired from specific soil types when seeding areas with unique soils or parent materials. For example, seeding fourwing saltbush on sandy, deep, well-drained soils should be done using seed produced on bushes growing on a similar site. On soils that have uniquely different soil textures, pH levels, drainage conditions, and fertility, specific ecotypes should be used.

Woodward and others (1984), working in Utah, found that dicotyledons (broadleaf herbs) tend to take up divalent ions more efficiently than monocotyledons (grasses), but monocots take up more monovalent cations than dicots. Also, the root cation-exchange capacity values for dicots were significantly larger than for monocots. The characteristic of root cation-exchange capacity helps to explain the differential distribution of grasslands and shrublands in common climatic zones. Differences in root cation-exchange capacity result in intense competition between monocots and dicots for certain minerals. This suggests that plants that are similar in root cation-exchange capacity coexist best. However, seeding grasses on soils deficient in magnesium but with adequate potassium would not be recommended, as it is unlikely that grasses would persist on these soils. In extensive areas where soils differing in mineral content exist, the use of adapted species is necessary.

Soils from the desert communities typically contain high levels of salts and have high pH levels. Few plants are adapted to these sites and only well-adapted species should be used. Attempts to convert these shrublands to grasses have not been successful. However, some grasses such as Russian wildrye and tall wheatgrass have proven adapted to specific sites and have been seeded to provide additional forage.

Planting introduced species and their varieties requires careful consideration of plant growth requirements. It is important that adapted species are planted, and marginally adapted substitutes are not planted. Also, it is unwise to convert unique plant communities to other species and growth forms following a major disturbance such as a wildfire.

Soil conditions directly affect seedbed features, which in turn influence planting success. Sites may be capable of supporting certain plant communities, but once the original vegetation has been removed or destroyed, the suitability of the site is altered. Native species that have evolved on the site may not be able to reestablish due to unstable soil conditions. It is not always correct to assume that native species can be easily established. For example, saline and alkaline soils, common in many valley bottoms, present unusual problems in preparing and maintaining a suitable seedbed. These soils absorb water slowly, are usually sticky when wet, and crust when dry (Pearson 1960). High levels of salt can cause physiological drought (Bernstein 1958). If vegetation is removed from these sites, they are extremely difficult to revegetate. Seedbed preparation methods often degrade soil structure. If soils are plowed, tilled, and left exposed, heavy crusting will occur and can prevent seedling emergence. Although these soils are capable of supporting a specific group of species, modifications to the area can reduce the success of artificial revegetation.

Disturbances on riparian sites also illustrate areas where disruption of the soils can alter the suitability of the site for establishing desired species. Disturbance of the vegetation can significantly affect soils and seedbed conditions, restricting the ability of certain species to establish (Platts and others 1987). These sites are usually flooded in the spring for long enough periods to damage the seedbeds. Also, many disturbed sites are subjected to siltation or erosion, creating unstable seedbeds.

Soil conditions directly influence species adaptiveness by affecting seedling establishment. Soils that are exposed to fires or heavy grazing are often altered (Eckert and others 1987). Changes in soil structure, presence of organic matter, standing crops and litter significantly affect the seedbed. Big sagebrush and winterfat have been difficult to establish on large open areas disturbed by fire due to disruption of the soil surface (Monsen and Pellant 1989).

Species Origin

Native Species—In general, native species have been more difficult to establish in large project plantings than selected introductions. Kilcher and Looman (1983) conclude that the factors limiting the use of natives are: (1) the lack of seed of local origin; (2) the variability in seed germination; (3) the physical difficulty in processing and seeding some native species; (4) unreliable emergence and establishment; (5) susceptibility to winter injury, especially with seed harvested outside the immediate area; (6) limited ability to compete with weeds during establishment; (7) low seed yields; and (8) comparatively high cost of seed. In most situations the limitations listed by these authors have and are being overcome, and the culture and use of native plants continue to increase in importance.

Recent plant selection programs have provided a wide complement of species for restoration or revegetation. Important advances have resulted in: (1) a larger number of native shrubs, broadleaf herbs, and grasses for artificial revegetation; (2) identification of specific ecotypes having important features and the determination of their areas of adaptation; (3) improvement of planting practices and seeding techniques; and (4) availability of better quality native seeds.

Native species can be recommended and used on range, watershed, and wildland sites with more confidence than in the past (see Section VII). Many important native shrub and forb species, ecotypes, and populations have been identified and can be recommended for planting. Notable advances have been made with some shrubs including big sagebrush, black sagebrush, fourwing saltbush, rubber and low rabbitbrush, Stansbury cliffrose, curlleaf mountain mahogany, Martin ceanothus, antelope bitterbrush, winterfat, skunkbush sumac, and green ephedra. Antelope bitterbrush has received the most attention (Ferguson 1983), but seed collection and sales from specific ecotypes of big sagebrush, rubber rabbitbrush, and fourwing saltbush are also quite important (Monsen and Stevens 1987; Shaw and Monsen 1990).

Considerable genetic variability exists in most native species, and selections have been used to enhance germination and establishment attributes, growth rates, growth habits, forage production, and quality (USDA Soil Conservation Service 1989). Currently, ecotypes of many important species can be recommended for seeding specific locations with different climatic and edaphic conditions. Programs have also been employed to propagate and increase ecotypes with important traits.

Figure 5—Site of origin for Lassen antelope bitterbrush.

Hybridization between varieties, ecotypes, and taxa have been used to enhance specific attributes of a number of woody species. Selection programs have been employed to promote features of fourwing saltbush, big sagebrush, antelope bitterbrush (fig. 5), low and rubber rabbitbrush, Stansbury cliffrose, curlleaf mountain and true mountain mahogany, and black sagebrush (McArthur and Welch 1986; Shaw and Monsen 1990; Tiedemann and Johnson 1983; Tiedemann and others 1984b). The importance of maintaining ecotypes with a broad genetic base has been recognized by Stutz (1985). Genetic diversity has been investigated through planting a number of populations or ecotypes at a problem site, and allowing natural selection to occur. This procedure has not been widely used, but represents an important consideration in planting native species over a wide range of sites.

New techniques for culturing many plants have significantly aided in their use. Regional seed companies now market seeds of a number of native species. In addition, seed vendors have developed more reliable collection, processing, and storage techniques to aid in providing a more stable supply of native seeds. Various wildland collection sites are now managed to produce seeds of different ecotypes. Consequently, seeds of a wider array of native species and a better and wider selection of species, advanced cultivars, and ecotypes are available for planting. The increased availability of seed has significantly reduced costs, and continued reductions can be expected. More reliable seed germination tests have been developed and standardized by seed laboratories (Stevens and Meyer 1990). Seed purity and germination standards have been developed to aid in seed marketing (Allen and others 1987; Kitchen and others 1989).

Seed Dormancy—Seeds of many native species collected from wildland sites germinate erratically depending upon year of collection, seed origin, and stratification treatments (Kitchen 1988; Silvertown 1984; Stevens and others 1981a). Seeds of many native species have embryo dormancy or impermeable seedcoats or both (Moore 1963; Schopmeyer 1974b). These features may delay and regulate germination and plant establishment (Meyer 1990). Seed dormancy is normally an advantage and aids in natural establishment of the species (Meyer and others 1990b). Dormancy may prevent seeds from germinating during periods when the chance of survival is low. Seeds of many species are not conditioned to germinate the first year after development, but persist, creating a seedbank from which new seedlings may occur over a number of years. Sporadic germination hinders development of uniform stands. Seeds of sumac, snowberry, Woods rose, and hawthorn, are difficult to germinate even if pretreated for extended periods. Seeds of other species are less difficult to germinate, but require quite different pretreatments to promote uniform germination. Unless adequately stratified, certain seedlots germinate so erratically that satisfactory stands generally fail to establish.

Seed dormancy obstacles in a number of native species have been overcome through selection and planting at appropriate seasons. Selections of 'Bighorn' sumac, 'Montane' mountain mahogany, 'Rincon' fourwing saltbush, and 'Cedar' Palmer penstemon have been developed, in part, for their favorable germination attributes (McArthur and others 1982). In addition, seeds from certain native collection sites are selectively harvested and sold because of favorable germination features. Land managers may not be aware of individual differences in germinability of all seedlots, but seeds can and should be tested to assure use of germinable sources. In addition, records should be maintained to document sources used in successful seedings.

Rate of germination is also an important attribute for planting success. The length of time required for seeds to germinate appears important to the establishment of species under arid situations.

Drought Tolerance—The success achieved in seeding arid, semiarid, and subalpine sites is most often dependent upon soil moisture conditions at the time of seedling emergence. Quite often soil moisture is only moderately favorable, and seedling survival is dependent upon the drought tolerance and physiological growth of seedlings (fig. 6). Considerable emphasis has been directed to the selection and use of drought-tolerant strains and ecotypes as many plantings are conducted in semiarid communities (Asay and Johnson 1980; Johnson and others 1982). Differences

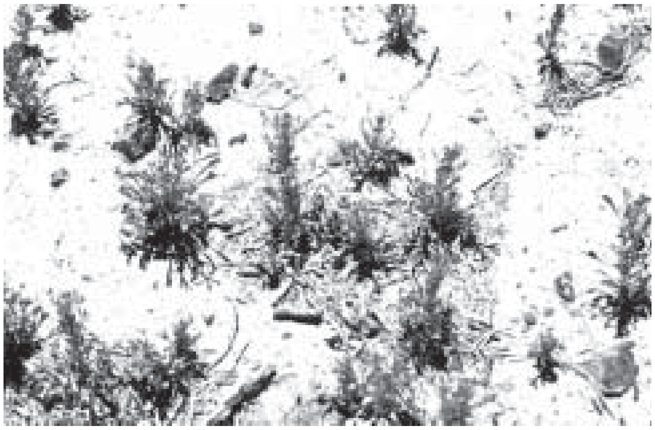

Figure 6—Big sagebrush seedlings. Drought tolerant and rapid rate of top and root growth is required for establishment in arid areas.

in seedling tolerance to drought varies significantly among collections, strains, and cultivars (Ford 1988; Wright and Brauen 1971).

If drought problems are anticipated, planting techniques should be used that help conserve moisture and assure protection of the less tolerant species. Establishment problems cannot be entirely rectified simply by planting the most adapted ecotypes. Seedlings of some species are especially sensitive to drought. Land managers should be aware of this and assure the creation of suitable seedbeds.

In the Intermountain area, drought frequently causes extensive dieoff of many plants (Harper and others 1990; Wallace and Nelson 1990). However, native species that have evolved under these circumstances express considerable tolerance of arid conditions. Selections of western wheatgrass and winterfat commonly used in wildland seedings are able to persist through periods of extended drought. Western wheatgrass, Sandberg bluegrass, purple three-awn, Idaho fescue, and bluebunch wheatgrass survived and increased during the drought periods of 1986-1989 in central Utah, when density of cheatgrass was significantly reduced. Certain introduced species, including Russian wildrye, also express excellent drought tolerance, and can be relied upon for seeding arid sites (Asay and Knowles 1985b).

Species seeded in arid sites must be adapted to periods of low moisture. Substitute species that are marginally adapted should not be used.

Growth Rates

Range and wildland seedings are currently based upon the use of species that have demonstrated the ability to establish and attain a reasonable stand in a relatively short time. In most seeding projects, species with rapid development are planted to furnish needed cover and forage (Davis and Harper 1990). Species that are capable of growing rapidly and can attain a mature stature in a short time are recommended in most seeding projects (Monsen and Turnipseed 1990). Plants with the ability to establish and grow quickly generally are better able to compete with weeds and survive periods of drought. Species that grow more slowly should be seeded separately from more aggressive species.

Species growth rate is important in maintaining plant composition and perpetuation of established stands. Seedling recruitment is required to perpetuate many species, and new seedlings must be able to compete with established plants. Species that are able to reproduce when growing with other plants usually are the ones that ultimately survive. Introducing aggressive and dominating plants to a composition of natives may not allow regeneration of the natives, and would not be recommended.

Cold Tolerance—Cold tolerance and resilience to frost generally are desired features of most plant species selected for revegetation in the Intermountain West. Cold tolerance is particularly important in young plants as seedlings usually emerge in early spring. Many young seedings are weakened or killed by spring frosts. Species with sensitive seedlings cannot be arbitrarily deleted from all seedings, but more cold-tolerant ecotypes should be seeded in areas where frost is a major problem. Seed sources of big sagebrush, winterfat, fourwing saltbush, and alfalfa are known to be highly sensitive to frost, and the most adapted ecotypes should be planted (Plummer and others 1968). Species with obvious intolerance to cold should be sown in late spring, if possible, to lessen losses from early spring frosts.

Palatability—Palatability and resilience to grazing are important features that can influence seedling establishment. Unmanaged grazing has frequently eliminated the more desirable species from mixed seedings. Unfortunately, only species having similar palatability traits are planted in some projects to limit problems associated with grazing management. Although this is a solution to grazing problems, the most appropriate species needed for other resources may not be planted.

New seedings normally attract concentrated use by many animals. Small mammals, insects, rodents, and often large game animals selectively graze small seedlings (Evans and others 1983). Young seedlings are extremely sensitive to heavy and repeated grazing. Livestock use can be regulated to protect new plantings. Wildlife populations are not as easily controlled, but reduction in animal numbers may be necessary to protect new plantings. Protection from heavy use must be provided until seedings are well established.

Some species require 2 to 7 years to fully establish and attain a stature that is able to persist with moderate use (Davis and Harper 1990; Monsen and Shaw 1983a). Less desirable ecotypes of certain shrubs and forbs can be sown to discourage grazing, but this may not be in line with the rehabilitation goals. In some situations, more resilient, but palatable, species might be sown to attract grazing and defer use from less resilient species. Seedings of alfalfa (fig. 1), yellow sweetclover, small burnet, orchardgrass, and mountain rye have been useful in providing desirable herbage from new plantings. It is most important that, whenever possible, areas seeded should be of sufficient size to dissipate grazing and lessen animal use. This may not be practical in all situations, especially on sites where wildfires or related disturbances determine the acreages to be seeded.

Animal use of emerging seedlings and young plants usually is not a problem on sites that support a remnant stand of native species. Remnant plants normally recover quickly following treatment. As these plants recover and produce new growth they attract use and aid in dispersing grazing pressure.

Persistence—Species that are able to persist under varied and often adverse climatic conditions, competition, and management impacts should be planted. Attempting to maintain a noncompatible composition of plants is ill-advised. Seeding aggressive, introduced understory herbs into many native communities has frequently resulted in the loss of most native species, coupled with a progressive increase of the seeded herb. The changes in plant composition may occur slowly, requiring many years to stabilize. Most problems have occurred when introduced species make up the major part of seed mixture. Although some introductions can enhance native communities, it is important that a natural balance in species composition is attained.

Value of Maintaining a Broad Genetic Base—In some situations, plants with desirable attributes are planted exclusively. Some strains have been developed through breeding or selection processes that may narrow the genetic base of the species, and eliminate other adaptive traits. Maintenance of a broad genetic base is recommended when seeding native species. Extensive dieoff of plantings attributable to the use of narrowly developed strains has not been widely detected. However, planting of a single seedlot or ecotype over a broad range of sites has often resulted in discernible patterns of success and failure. It should not be assumed that strains or selections with certain favorable traits are universally adapted to all sites. Plantings should not be confined to the use of seed from one very restricted population, or from only a limited number of individuals.

Seeds of many native species are often gathered from small, confined areas where soil moisture or other conditions favor seed production. Considerable amounts of seed are often collected from favorable sites, yet may not include the diverse attributes of the broader population.

Native species grown under cultivation may also have been propagated from seed of a few individuals. Seed that is commercially sold is normally collected or reared from bushes that are high seed producers and are easily harvested. These features may not represent the most desirable traits necessary to assure survival of the species.

Land managers cannot regulate or maintain direct control over the collection and sale of all seeds, but attention should be given to the origin of the seed acquired, and conditions at the rearing locations.

Adaptability of Released Cultivars—All plant cultivars have been developed for specific planting conditions. All have particular attributes or features that differ from the norm and encourage their use (USDA Soil Conservation Service 1989b). The selection and development of ‘Rincon’ fourwing saltbush was instigated, in part, because of the small utricles and early, uniform germination attributes. Stand establishment of ‘Rincon’ is usually more predictable than for other ecotypes (Monsen and McArthur 1985). However, it is not advisable to seed this cultivar on sites where it is not adapted. Also, it is obvious that cultivars are not universally superior in all traits to all other selections or collections of a species. Seedings should not be restricted to released cultivars, but seed sources should be determined on a case-by-case basis. Planting of ‘Rincon’ fourwing saltbush on low arid sites has not been successful, and the ecotype has not proven as well adapted to these areas as native ecotypes. Similar results have been recorded when Lassen antelope bitterbrush and ‘Hatch’ winterfat were planted on sites to which they are not adapted.

All cultivars have been carefully evaluated and their performance can be predicted. The quality of certified seed is usually good. However, each cultivar should be examined and used for the purpose for which it was developed. (See discussion of individual species and their cultivars in chapters 18-23.)

Seeding Mixtures or Single Species

Wildland restoration projects are usually conducted to reestablish native plant communities. This is not always possible as seeds or planting stock of many species are unavailable, and knowledge or techniques required for planting some species is lacking. Also, costs currently limit certain planting measures. However, advances in methodology continue to permit use of a greater complex of native species. As techniques are further developed, complete reestablishment of native plant communities may be possible.

Not all revegetation work is designed to reestablish native plants. In many range plantings introduced species are primarily used to increase forage yield and quality, and to accommodate management practices. In these situations, only a limited number of introduced species may be used.

Rehabilitation programs that are designed to provide livestock forage, watershed, and wildlife values have, to date, included a preponderance of introduced grass and broadleaf herbs. Introduced species are more readily available, seedlings establish more successfully, and forage values are better understood.

In most range seedings the trend has been to seed single species or simple mixtures. Revegetation efforts to satisfy wildlife, watershed, and reclamation needs include a wider array of species, and rely upon the restoration of native plants. In general, the advantages reported for seeding a single species or a limited number of plants apply primarily to the use of introduced forage grasses, and do not apply to seeding other species. Hughes and others (1962), Hull and Holmgren (1964), and McIlvain and Shoop (1960) reported that single species or simple mixtures are more easily managed if species with similar palatability, growth response, and grazing tolerance are used. However, native rangelands consist of a complex array of species that have persisted with natural use. Communities are only upset when seriously mismanaged.

Harris and Dobrowolski (1986) concluded that species mixtures in range seedings planted in northeast Washington are unstable, and that monospecific populations of suitable species, selected to fit seasonal grazing, should be seeded separately. Plantings should be fenced and used separately in a managed grazing system. Their studies reported that hard fescue eventually dominated most planted mixtures. Cook (1966), Currie and Smith (1970), Hull (1971a), and Vallentine (1989) concluded that the relative palatability of the species used determines the future of species in a mixture. Grazing animals tend to concentrate use on more palatable species, eventually reducing or killing them. Regulating the grazing season and period of use has not prevented the selective loss of more palatable species. Cook (1966) also concludes that seeding mixtures to furnish palatable species throughout the grazing season generally failed because all of the species cannot be maintained.

These conclusions are based on the assembly of forage grasses planted primarily for grazing by cattle. The implications are not directly applicable to wildlife or multiple uses. In addition, the results have questionable application to range seedings where different species are planted. Van Epps and McKell (1977) found that interseeding shrubs with grasses on semiarid ranges improved the quality of forage consumed by livestock, particularly in the fall and winter (fig. 7). Gade and Provenza (1986) found that sheep grazing on shrub and grass pastures in central Utah increased their forage intake by 36 percent and the forage consumed contained about 35 percent more crude protein than when the sheep grazed crested wheatgrass alone. The response of species when seeded in mixtures is directly related to grazing pressure and livestock management. Revegetation of most wildland occurs on sites having a variety of aspects, soils, and moisture conditions; mixed seedings are necessary to populate the area (Plummer and others 1968). Rechenthin and others (1965) reported that native rangelands in good condition are best seeded to native species at approximately the same ratio as found in the native community.

Regardless of the problems inherent in the use of mixtures, it is apparent that combinations of species should be seeded. Balancing the use of introduced and native plants must be considered on a case-by-case basis. As additional information is gathered, more precise species mixtures will, undoubtedly, be developed. Following are some specific considerations for selecting and using species mixtures, or using a single or a limited numbers of species.

Advantages of Planting Mixtures

Maintenance of Diverse Plant Communities—Most seedings are conducted on sites that have diverse microclimates, with varied soil and moisture conditions (Gifford 1975). Different plant communities appear, and different species are used to restore

Figure 7—Big sagebrush interseeded into crested wheatgrass to increase forage quality and quantity for livestock and big game.

various plant communities. Soil temperatures, fertility, and aspect differ among microsites, and different plant species are adapted to the various microsite conditions. Therefore, a number of species are needed to adequately populate the entire area.

Many areas have been dramatically abused, and some native species have been eliminated. Neither existing plants nor a seedbank remain to repopulate the site. Consequently, plant communities must be reconstructed by seeding or planting.

Encouraging Successional Changes—Most plant communities are created through successional changes (Eckert and others 1987). Although some species and communities can be established directly by seeding, natural shifts in species density and composition occur. Seedings of crested wheatgrass and intermediate wheatgrass establish quickly and persist for extended periods. In contrast, plantings of timothy and mountain brome establish quickly, but weaken after a number of years and may be invaded and replaced by other species. Seedings of Wyeth eriogonum, Lewis flax, and Pacific aster establish moderately well, but gain in importance even amid considerable competition. Many native shrubs establish slowly, but after attaining maturity may dominate the site.

Planting species that may restrict natural successional processes is not advised. Also, misuse of planting sites can disrupt successional changes. Desired changes can be adversely affected if weedy species are not removed or reduced at the time of planting, and desired species are unable to establish. The composition of species that initially establish following seeding sets the stage for future changes in species composition. Although restoration plantings are designed to restore entire communities, the proper assembly of species and seeding rates are not known. Plantings are currently being conducted using the most desired species expecting natural succession will ultimately result in a natural grouping of species.

Improves Weed Control—Seeding a mixture of species usually improves the control of undesirable weeds. Many individual species are extremely aggressive, and if planted alone can quickly control weedy plants (Torell and Erickson 1967). However, mixtures normally enhance weed control over diverse sites.

If plantings are designed to control annual weeds, early growing species usually must be planted (Foster and McKay 1962). Certain summer annuals are not entirely controlled by early spring species. Plants that establish and grow during late spring and early summer are more competitive with these weeds.

Seeded species must be able to restrict seedling establishment of weedy plants, and must be able to reduce or prevent spread by vegetative reproduction. Many perennial weeds may not be quickly eliminated by competition from seeded species, but their density and spread can be contained.

Reduces Risks of Establishment—Seeding a number of species together helps to ensure the establishment of a desirable stand. Many species, including Canada bluegrass, small burnet, slender wheatgrass, bottlebrush squirreltail, and crested wheatgrass have excellent establishment attributes. Consequently, any one of these species can be seeded alone. Few species establish as well as these plants, and seeding combinations increases the chance of success. Climatic conditions are often so erratic that seeding a single species over a wide variety of sites may result in poor stand establishment.

Mixtures should not be indiscriminately assembled, but a desirable number of species should be sown. Although weak stands may appear, mixed plantings generally improve over time.

Satisfy Multiple Uses—Use of a number of species provides the vegetative base necessary to support a variety of resource needs (Cook 1962). Revegetation and restoration efforts may be designed to enhance watershed, wildlife, or aesthetic conditions. In most situations, a single species is not able to provide such diverse needs. Even when the objective is to furnish forage for livestock, multiple species mixtures should be used. Seeding with multiple species provides longer periods when succulent forage is available (table 1). Land uses often change, and forage and cover requirements also change. Revegetation and restoration goals should not be limited to immediate uses, but should take into consideration future needs. Once a seeding is established, it becomes expensive and difficult to change.

Watershed and ground cover—Planting combinations of species having different growth habits furnishes a storied array of species that usually provides better ground cover throughout the entire year (USDA Soil Conservation Service 1954). Shrubs and trees with an upright stature entrap snow and delay snowmelt and runoff. Herbaceous plants normally furnish dense ground cover. Mixtures also contribute to a variety of plant litter, which provides soil protection and site stability.

Wildlife habitat—Game and nongame habitat consists of a variety of forage and cover plants. Species should be planted that can furnish seasonal cover as well as nutritious herbage at different seasons. Not all plantings will be designed to furnish a mixture of resources, but each planting site contributes to the overall needs of wildlife. Consequently, it is important to assure that all aspects of wildlife habitat are enhanced by rehabilitation measures. Sites that provide seasonal wildlife habitat should be seeded to assure animal needs are satisfied.

Table 1—Duration of succulence for selected grasses, forbs, and shrubs.

Species	Periods of succulence			
	Mar-May	**Jun-Aug**	**Sep-Nov**	**Dec-Feb**
Grasses				
Brome, smooth	xxxxxxxxxxxxxxxx[a]		0000[b]	
Fescue, hard sheep	xxxxxxxxxxxxxxxx		00	
Fescue, red	xxxxxxxxxxxxxxxx00000000000			
Orchardgrass	xxxxxxxxxxxxxxxxxxxxxxx		0000000000	
Ricegrass, Indian	xxxxxxxxxxxxxxxxxx		00000000	
Rye, mountain	xxxxxxxxxxx		00000000	
Timothy	xxxxxxxxxxxxxxxxxxx		000000000	
Wheatgrass, bluebunch	xxxxxxxxxxxx		00000	
Wheatgrass, crested	xxxxxxxxxxxx		0000000	
Wheatgrass, standard crested	xxxxxxxxxxxx		00000	
Wheatgrass intermediate	xxxxxxxxxxx		000000000000	
Wheatgrass, pubescent	xxxxxxxxxx		00000000	
Wheatgrass, tall	xxxxxxxxx		0000000	
Wildrye, Great basin	xxxxxxxxxxxx		000000	
Wildrye, Russian	xxxxxxxxxxxxxxxxxxxxxxx0000000000000000000			
Forbs				
Alfalfa	000000xxxxxxxxxxxx00000000000000000000000000000000			
Balsamroot, arrowleaf	xxxxxxxxxxx			
Burnet, small	000000xxxxxxxxxxxxxxxxxxxxxxxxxxxx00000000000000000000000000			
Flax, Lewis	00000xxxxxxxxxxxxxxxxxxxxxxxxxxxx0000000000000000000000000000			
Geranium	xxxxxxxxxxxxxxxxxxxxxxxxx000000000			
Globemallow	xxxxxxxxxxxxxxxxxxxxxxxxxxx00000000000			
Goldeneye, showy	xxxxxxxxxxxxxxxxxxxxxxxxxxxxx000000			
Milkvetch, cicer	000000xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx00000000000			
Penstemon, Palmer	0000xxxxxxxxxxxxxxxxxxxxxxxxxxxx0000000000000000000000000			
Penstemon, Rocky Mountain				
Sainfoin	0000xxxxxxxxxxxxxxxxxxxxxxxxxxxx00000000000			
Sweetvetch, Utah	xxxxxxxxxxxxxxxxxxx0000000000000000000000000000			
Shrubs:				
Bitterbrush, antelope	00000xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx00000000000			
Cliffrose, stansbury	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Ephedra, green	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Mountain mahogany, curlleaf	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Mountain mahogany, true	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Rabbitbrush, rubber	00000xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx0000000000000000000			
Sagebrush, big	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Sagebrush, black	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Saltbush, fourwing	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Shadscale	xxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Serviceberry, Saskatoon		xxxxxxxxxxxxxxxxxxxxxxxxx		
Winterfat	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			

[a]XXXX = Most leaves and seed stalks are green.
[b]0000 = Only basal or overwintering leaves remain green.

Certain sites may offer limited wildlife benefits, and less diverse plantings will suffice. However, few sites are void of some form of wildlife, and species mixtures are usually necessary.

Forage production and quality—Grazing animals seek diversity. Forage resources are generally improved by selection of species mixtures. Certain sites may not support many species and a single species may be sown to ensure persistence of an adapted cover. However, mixed plantings usually provide more herbage, and seasonal production is greatly enhanced (Gade and Provenza 1986; Hughes and others 1962). Mixed plantings also improve forage quality (Gomm 1964; Van Epps and McKell 1977). For example, planting shrubs with herbs enhances both winter and summer forage conditions. Where possible, mixtures should be used to extend the season of use, increase herbage yields, and improve seasonal quality of forage.

Aesthetics—Nearly all rehabilitation efforts affect the appearance of the area treated for extended periods. Planting species that are compatible with adjacent undisturbed sites is recommended. It is usually necessary to seed mixtures to reestablish a significant density and distribution of species that will blend with adjacent areas.

Little research has been done on the use of revegetation to improve aesthetics. Planting native communities is usually regarded as the best method to reestablish natural appearance. However, some sites and circumstances do not facilitate reestablishment of natives. Thus, plant communities must be reconstructed using species that closely resemble the natives.

Adding species to a mixture to assure improvement of aesthetics may reduce forage production or lessen other resources. However, in most seedings forage species usually dominate, and aesthetic values are not fully considered—a practice that should be corrected.

Factors Suggesting Use of a Single Species

Certain plantings favor the use of one or only a few species. Normally, single-species plantings are restricted to specific sites, soil conditions, or to satisfy specific resource needs. In some situations, only a few species may be capable of growing on the planting site (McArthur and others 1987b). Soil or climatic conditions may limit the number of adapted species (Blaisdell and Holmgren 1984). Planning a broad complex of species on these sites is usually a waste of seed and effort.

Sites that could support a number of species are frequently seeded to only a few, but this should be done only after careful consideration of all circumstances. Some factors do influence the decision to plant only a few species. Following are some reasons for limiting the number of species used.

Ease of Planting—Seeding a single or only a few species is usually much easier than planting a complex mixture. If only two or three species with similar seed size, germination, and establishment attributes are sown, planting techniques are simple (Vallentine 1989). Planting methods that are available and can be used often determine the species used. The use of a number of seeding practices is often rejected as being too complex and difficult. In many cases only one seeding practice (drilling, broadcasting, interseeding) is selected and employed. Species that cannot be included in a common mixture and planted in one operation are thus eliminated from the revegetation plan. Although planting one or two species may be quite simple, it is important that the species selected and procedures used are not dictated by convenience.

Planting Costs—Selection of site preparation and revegetation methods used on wildland sites are often restricted by the costs involved. Using a number of species may require using two or three planting practices. It is costly to treat small areas with one piece of equipment, and then use different equipment on adjacent sites. A project must often be quite large, and resources values high, to justify using a number of revegetation practices.

Aid in Seedling Establishment—Not all species can be established satisfactorily when seeded in mixtures (Horton 1989). Certain species of shrubs are particularly sensitive to competition from broadleaf herbs and grasses. These shrubs should be seeded alone or with a limited amount of understory herbs. Also, the presence of weedy plants often reduces establishment of seeded species, and only the most competitive plants can be sown in some situations (Jordan 1983).

Shrub-Herb Plantings

Species Compatibility

Most wildlife habitat improvement projects and restoration plantings differ from the typical livestock range improvement programs since a wider number of species having different growth forms are planted. Generally, most projects include a mixture of woody and herbaceous species. In contrast, range seedings emphasize the use of a limited number of herbaceous plants, principally grasses. Most species of grasses used in range and wildlife plantings establish well and develop rapidly. These traits are beneficial, and encourage the use of these plants. However, aggressive growth habits of many seeded herbs may create problems if slower developing species are also planted.

The problem is further complicated when seedings are conducted on steep, rocky, or inaccessible terrain where site preparation and seeding practices are limited.

Mixed plant communities occupy most wildland sites. Plant composition of these sites undoubtedly developed through various stages of plant succession. Natural changes in plant communities are not fully understood, and attempts to duplicate successional changes through artificial restoration are not always successful.

Seedling Status—The primary factor influencing species compatibility is the degree of competition exerted upon small, developing seedlings. If seedlings or young transplants are able to establish, their presence is most likely assured. However, if competition restricts or limits survival, plant density and composition are critically affected. Few species have been carefully evaluated to determine their compatibility with other commonly seeded plants. However, guidelines related to the establishment attributes and competitive traits of some species have been developed, and the ratings and evaluations are provided (table 2; also, tables in chapter 17). Matching the most compatible species together is essential for the success of mixed plantings. Species that are able to establish well and compete in mixtures are generally the most widely recommended species used. Seed mixtures recommended for various plant communities are presented in chapter 17. These recommended mixtures have been developed based upon compatibility among species during stages of community development.

Some species of grasses, including Indian ricegrass, and western wheatgrass establish slowly and are less competitive with seedlings of other species. Their presence, or addition to seed mixtures, better assures the establishment of associated species than if more aggressive grass species are sown.

Competition in Mature Communities—Natural regeneration and change in species composition occur after plants gain maturity. Many species are long-lived, but natural reproductive or vegetative spread are essential to their survival. New seedlings must be able to establish and survive amid competition within mature communities (fig. 8). The entry and survival of new seedlings are often dependent upon disturbances caused by rodents, climatic events, and fires. These disturbances may "open up" small areas and favor seedling establishment.

Seedling establishment of some species may benefit from the presence of associated plants. Competition may limit natural seedling recruitment, even though some seedlings are able to establish in most years. During years of favorable conditions, seedling survival may be quite high. Monsen and Shaw (1983c) found throughout a 40-year period that natural reproduction of antelope bitterbrush occurred regularly on sites supporting an understory of native grasses and broadleaf herbs. A sufficient number of shrub seedlings established to maintain stand density. Monsen and Pellant (1989) reported that the presence of Sandberg bluegrass significantly improved the natural reproduction of winterfat on sites with a preponderance of cheatgrass.

The seedbed and soil surface conditions created by existing plants frequently benefit seedling establishment. Soil microsites beneath the crowns of undisturbed big sagebrush shrubs are favorable to seed entrapment and establishment of small seedlings (Eckert and others 1987). The overstory canopy and litter provided by Gambel oak, quaking aspen, and Rocky Mountain maple enhance seedbed conditions for understory herbs (Plummer and others 1968).

Species that are highly ranked in regard to natural spread are plants that can increase in density amid mature plant communities (tables 2; also, tables in chapter 17). Plants with unusual ability to spread are not restricted to species normally growing under the most favorable climatic conditions. Seedlings of Apache plume, and black sagebrush are able to spread quite well in somewhat arid environments.

Natural reproduction and changes in species composition are related to climatic conditions, and seedling establishment may occur quite erratically. Seedling establishment is not always confined to years or seasonal periods of high moisture. From 1988 to 1990 considerable increases in density of perennial grasses occurred in southern Idaho and central Utah on sites previously dominated by cheatgrass. This increase occurred during years of drought when annual weeds were unable to establish and produce seed crops.

Benefits of shrub-herb associations—In situations where shrubs and herbs normally occur together, there are benefits in maintaining these associations. Species that have evolved together undoubtedly benefit by the relationship, or are sufficiently compatible to survive. In addition to the benefits derived from favorable seedbeds provided by associated plants, mixed communities also influence other factors related to perpetuation of a seeded community. The presence of compatible understory herbs frequently prevents the invasion of weeds that can upset natural regeneration processes. Understory plants of Idaho fescue, purple three-awn, bluebunch wheatgrass, Thurber needlegrass, and western wheatgrass are capable of preventing the invasion of annual grasses and summer annual broadleaf weeds. Maintaining a healthy understory of perennial herbs has been essential to the natural reproduction of stands of antelope bitterbrush, big sagebrush, Stansbury cliffrose, winterfat (fig. 9), and curlleaf mountain mahogany.

Table 2—Seeding requirements and seedling characteristics of some major species.

Species	Date of seeding[a]	Method of seeding[b]	Depth of seeding[c]	Compatability with other species[d]	Seedling vigor[e]	Seedling growth rate[f]
Grasses						
Bluegrass, Sandberg	F-S	A-B	A	5	4	4
Brome, mountain	F-S	A-B	B	5	5	5
Brome, smooth	F-S	A-B	B	4	4	3
Canarygrass, reed	F-S	A-B	B	4	2	4
Dropseed, sand	F-S	A-B	C	2	3	4
Fescue, hard sheep	F-S	A-B	B	3	3	3
Needlegrass, green	F-S	A-B	B	3	3	3
Oatgrass, tall	F-S	A-B	B	4	4	4
Orchardgrass	F-S	A-B	B	4	4	4
Ricegrass, Indian	F	A-B	D	3	3	3
Rye, mountain	F-S	A-B	B	5	5	5
Squirreltail, bottlebrush	F-S	A-B	B	4	5	4
Timothy	F-S	A-B	B	4	4	4
Wheatgrass, bluebunch	F-S	A-B	B	2	2	3
Wheatgrass, crested	F-S	A-B	B	2	2	3
Wheatgrass, standard crested	F-S	A-B	B	5	5	4
Wheatgrass, intermediate	F-S	A-B	B	5	5	5
Wheatgrass, pubescent	F-S	A-B	B	4	5	4
Wheatgrass, western	F-S	A-B	B-C	3	3	3
Wheatgrass, tall	F-S	A-B	B-C	3	4	4
Wildrye, Great Basin	F	A-B	B	2	2	2
Wildrye, Russian	F-S	A-B	B	3	2	2
Forbs						
Alfalfa	F-S	A-B-C-D	B	4	4	5
Aster, blueleaf	F-S	A[g]-B-C-D	A	4	4	4
Balsamroot, arrowleaf	F	A-B-C-D	B-C	2	3	1
Burnet, small	F-S	A-B-C-D	B	4	5	5
Crownvetch	F	A-B-C-D	B	3	3	3
Flax, Lewis	F-S	A-B-C-D	A-B	5	4	4
Globemallow	F	A-B-C-D	B	3	3	3
Goldeneye, showy	F-S	A-B-C-D	A-B	4	2	2
Lupine	F	A-C-D	B-C	3	4	4
Milkvetch, cicer	F	A-B-C-D	A-B	4	4	3
Penstemon, Palmer	F	A-B-C-D	A-B	5	4	3
Penstemon, Rocky Mountain	F	A-B-C-D	A-B	4	4	3
Sainfoin	F-S	A-B-C-D	B-C	4	4	3
Sweetclover, yellow	F-S	A-B-C-D	A-B	5	5	5
Sweetvetch, Utah	F	A-B-C-D	B	3	2	3
Shrubs						
Bitterbrush, antelope	F	B-C-D	B-C	4	5	4
Chokecherry	F	B-C-D	B-C	2	2	2
Cliffrose, Stansbury	F	B-C-D	B-C	3	3	2
Currant, golden	F	A-B-C-D	A-B	5	3	5
Elderberry, blue	F	B-C-D	A-B	2	2	3
Ephedra, green	F	B-C-D	B	3	2	2
Greasewood, black	F	B-C-D	B	2	3	2
Kochia, forage	F-S	A-B-C-D	A	5	5	3
Mountain mahogany, curlleaf	F	B-C-D	B	3	3	3
Mountain mahogany, true	F	B-C-D	B	3	3	3
Oak, Gambel	F	C-D	C	1	2	2
Rabbitbrush, low	F-S	A-B[g]-C[h]-D[h]	A	5	5	4
Rabbitbrush, rubber	F-S	A-B[g]-C[h]-D[h]	A	5	5	4
Sagebrush, basin big	F-S	A-B[g]-C[h]-D[h]	A	3	4	4
Sagebrush, black	F-S	A-B[g]-C[h]-D[h]	A	3	5	4
Sagebrush, mountain big	F-S	A-B[g]-C[h]-D[h]	A	4	5	4
Sagebrush, Wyoming big	F-S	A-B[g]-C[h]-D[h]	A	3	4	4
Saltbush, fourwing	F	A-B-C-D	A-B	3	4	4
Shadscale	F	B-C-D	B	2	2	2
Serviceberry, Saskatoon	F	C-D	B	3	3	3
Sumac, skunkbush	F	C-D	B	2	2	2
Winterfat	F-S	A-B[g]-C[h]-D[h]	A	4	5	3

[a]F = fall to winter; S = early spring.
[b]A = aerial or ground broadcast; B = drill; C = surface compact seeding; D = browse interseeder.
[c]A = surface to 0.12 inch (3.0 mm) deep; B = 0.12 to 0.25 inch (1.6 to 6.4 mm) deep; C = 0.25 to 0.75 inch (6.4 to 19 mm) deep; D = greater than 0.75 inch (19 mm) deep.
[d]1 to 5 with 5 being highly compatible.
[e]1 to 5 with 5 having high seedling vigor.
[f]1 to 5 with 5 having the highest rate of growth.
[g]If cleaned to 60 percent or greater purity.
[h]If cleaned to 30 percent of purity.

Figure 8—Natural recovery of native species. New seedlings must be able to survive amid competition from established plants.

Value of legumes in species mixtures—Legumes have been widely used as agricultural crops and in cultivated pastures. The addition of legumes to grass seedings has resulted in an increase in herbage production and an improvement in forage quality (Gomm 1964; Hughes and others 1962). Legumes supply soil nitrogen that can be used by associated plants (Derscheid and Rumbaugh 1970; Holland and others 1969; Nutman 1976). For these reasons legumes have been actively promoted for range and wildlife plantings.

Many introduced and native legumes have been evaluated for rangeland and disturbed land plantings. Legumes do occur in most native communities, and should be planted in restoration projects. They may be important in the recovery of native communities, but are more commonly used to provide forage or restore harsh mine sites or related disturbances.

Species of alfalfa, including common alfalfa and sicklepod alfalfa, have been the most successful broadleaf herbs for range and wildland seedings (Dahl and others 1967; Kilcher and Heinrichs 1966b; Lawrence and Ratzlaff 1985). Alfalfa is primarily used for its forage value. Nitrogen fixation has been observed to benefit associated plants, but rangeland varieties have not been developed for this characteristic. Few other species are comparable to alfalfa for establishment traits and forage value (Lorenz and others 1982). Most strains are adapted to sites receiving at least 12 to 14 inches (305 to 355 mm) of annual moisture. Once established, alfalfa survives periods of drought and considerable grazing (Rosenstock and others 1989).

Figure 9—Aerial seeded winterfat stand and considerable natural spread that followed.

Root-proliferating or rhizomatous cultivars have proven well adapted to semiarid regions (Berdahl and others 1986). The most successful cultivars include: 'Nomad'; 'Rambler'; 'Rhizoma'; 'Sevelra'; 'Teton'; 'Travois'; 'Roamer'; 'Drylander'; 'Spreader II'; and 'Kane' (Lorenz and others 1982). Strains with spreading root systems are able to recover from root damage caused by gophers. 'Nomad', 'Rambler', and 'Ladak' have been the most widely used strains throughout the Intermountain Region. 'Ladak' has preformed extremely well in pinyon-juniper, mountain brush, and big sagebrush sites in Utah. It is not considered a decumbent form, yet it withstands grazing and persists much better than cultivated field varieties (Heinrichs 1975). Berdahl and others (1986) concluded that the slow regrowth after grazing, and dormancy during long dry and cold periods are traits that contribute to the survival of dryland types.

Alfalfa provides excellent forage to all classes of grazing animals and is widely planted to provide high quality, palatable forage (Rumbaugh 1983). It has been planted in the foothills to draw big game animals away from cultivated farms and residential areas and is particularly well adapted to seeding with grasses. It establishes well, but seedlings are vulnerable to spring frost. Alfalfa is also very compatible with native herbs and grasses. It has usually been seeded in mixtures at rates up to 2 lb per acre (2.25 kg/ha). More recently, seeding rates of 2 to 5 lb per acre (2.25 to 5.63 kg/ha) have been used, with the amount of grass seed in the mixture being decreased significantly. In some earlier seedings, alfalfa was sown at 0.25 lb per acre (0.25 kg/ha). At this low seeding rate the plants were excessively grazed. Increasing the seeding rate to 2 to 4 lb per acre (2.25 to 4.5 kg/ha) significantly increases the density and forage production, and reduces concentrated grazing. Using alfalfa at these higher rates has not restricted the recovery of native herbs and shrubs. In fact production has been increased by higher seeding rates.

Kilcher and others (1966) concluded that on dryland sites in the northern Great Plains, seeding more than one grass with alfalfa had little advantage; however, reliance on one or two species for most range or wildland plantings is not advisable. Alfalfa has been eliminated by selective grazing when seeded in mixtures with grass and grazed with livestock. Use of alfalfa in range and wildlife planting in the Intermountain Region has improved yields, and with proper management the legume has persisted even under heavy use by game, livestock, rodents, and insects (Rosenstock and others 1989).

Other exotics, including cicer milkvetch, crownvetch, birdsfoot trefoil, and sainfoin have improved grass plantings, but their areas of adaptation are more limited than alfalfa (Hafenrichter and others 1968; Heinrichs 1975; Nichols and Johnson 1969; Plummer and others 1968; Townsend and others 1975; Wilton and others 1978).

Kneebone (1959) concluded through extensive trials that native legumes offer little promise for range use. However, considerable use has been made of Utah sweetvetch in range and wildland seedings (Ford 1988). Establishment features have been improved, and nitrogen fixation and areas of adaptability have also been evaluated and selections developed with superior attributes (Redente and Reeves 1981). The release 'Timp' is now available.

Seeding some native legumes has resulted in improvement of stand density, vigor, and forage production of associated species (Dahl and others 1967; Johnson and others 1983). In addition to Utah sweetvetch, plantings of silky lupine have been successful. Excessive animal use has not occurred with either of these two forbs, and they have demonstrated excellent longevity. Other native legumes are very important but have not been widely planted.

Considerable progress in development of other native forbs has resulted in the wide use of Lewis flax, Palmer penstemon, globemallow, showy goldeneye, sweetanise, arrowleaf balsamroot, Rocky Mountain penstemon, nineleaf lomatium, and Pacific aster. Contrary to earlier reports (Heinrichs 1975; Kneebone 1959; Vallentine 1989) native herbs have been found to have excellent forage characteristics. Many selections cure well and provide useful year-around herbage. In general, these species are easily established and current revegetation projects can be seeded with the appropriate herbs.

Some nonleguminous plants, including various shrubs, are associated with nitrogen-fixing organisms and improve soil fertility (Becking 1977; Hoeppel and Wollum 1971; Klemmedson 1979; Nelson 1983; Rose and Youngberg 1981). The list includes various species of alder, buckbrush, cliffrose, elaeagnus, and buffaloberry. Various woody legumes fix nitrogen, and understory species benefit from association with these shrubs (Becking 1970; Bermudez-DeCastro and others 1977). Including these species in range and wildlife plantings improves stand establishment and long-term productivity.

Seeding Rate

Sufficient seed should be used to assure the development of a good stand, yet at the same time prevent the waste of seed. Use of excessive seed amounts is needless and expensive. It can result in considerable seedling competition within and among seeded species, and can lead to high seedling mortality and even seeding failures. On the other hand, skimpy seeding may jeopardize establishment of good stands or individual species. This is not economically wise when considerable money has been spent to prepare the site. Hull and Holmgren (1964) listed three disadvantages of low seeding rates: (1) a longer period is required for the seeding to reach maximum productivity; (2) thin stands are more subject to invasion by undesirable species; and (3) robust and unpalatable plants tend to develop, plant distribution is irregular, and subsequent use is uneven.

Seeding rate can be influenced by species included in the mixtures, seed size (table 3), purity, viability, type and condition of seedbed, method of seeding, amount of competing vegetation present at time of seeding, and project objectives. Ease of establishment varies greatly among species. Number of seedlings established from a given number of seeds can be greater for fairway crested wheatgrass, alfalfa, small burnet, and smooth brome than for cicer milkvetch, Russian wildrye, western wheatgrass, and arrowleaf balsamroot.

Seed Quality

The amount of seed sown is influenced by the quality of seed to be planted. Seeds of many species are grown under cultivation, and acceptable seed purity and germination standards have been established. Both State and Federal seed certification standards have been established to assure that viable, high quality seed is sold and planted. Seed is certified on a State-by-State basis, and administered by an agency organization such as the Crop Improvement Association, the State Department of Agriculture, or the Agriculture Extension Service (chapter 27).

Various strains and varieties of individual species that have superior attributes have been developed through selection and breeding programs. These items may be released for sale as named cultivars. Numerous cultivars are currently available for range and wildlife plantings. Seed that is produced and sold as certified seed has been produced under specific field conditions to insure genetic purity, and has been cleaned and processed to meet minimum standards of germination, purity, and the absence of weed seeds. Certified seeds are grown, processed, and sold under supervision of State regulatory agencies. They are bagged and labeled with identifiable tags and sealed to prevent the bags from being opened unofficially. The tags provide information of State certification, crop variety name, and the grower's lot number. The certified seed must also include a label showing germination, date tested, weed seeds, and so forth. Seed certification and labeling laws have worked well to assure the availability of high quality seed.

Considerable amounts of noncertified seed are also grown and sold, but are not likely to be a genetically pure line, variety, or cultivar. Noncertified seed should also be tested and labeled to indicate the germination and purity of the seedlot. In addition, seed should meet standards related to the presence of noxious weed seeds. Noncertified seed is referred to as "commercial" or "common" seed and is often advertised as meeting certified seed standards. However, seed that has not been certified will probably not be genetically identical to a certified variety.

Harvesting and sale of native species has grown rapidly in recent years, creating a new series of problems related to seed quality standards and verification of seed origin. Seed quality standards are being constantly updated to standardize seed laboratory testing, and provide uniformity in the procedures and techniques used to determine seed germination, viability, and purity.

Table 3—Number of seeds per pound for selected grasses, forbs, and shrubs as compared to number of seeds per pound in fairway crested wheatgrass.

Species	Number of seed per lb	Pounds of seed required to equal the number of seeds in one pound of fairway crested wheatgrass
	100 percent purity	
Grasses		
Bluegrass, Kentucky	1,525,000	0.21
Brome, mountain	135,600	2.46
Brome, smooth	106,000	3.00
Fescue, hard sheep	633,500	0.50
Orchardgrass, 'Paiute'	600,000	0.53
Ricegrass, Indian	188,300	1.70
Wheatgrass, fairway crested	319,600	1.00
Wheatgrass, intermediate	88,100	3.63
Wheatgrass, pubescent	102,800	3.11
Wheatgrass, standard crested	192,800	1.66
Wildrye, Great Basin	130,700	2.45
Wildrye, Russian	210,000	1.52
Forbs		
Alfalfa	213,800	1.49
Balsamroot, arrowleaf	55,200	5.79
Burnet, small	55,100	5.80
Flax, Lewis	278,300	1.15
Milkvetch, cicer	113,700	2.81
Penstemon, Palmer	609,700	0.52
Sainfoin	26,300	12.15
Sweetclover, yellow	258,600	1.24
Shrubs		
Bitterbrush, antelope	20,800	15.36
Cliffrose	64,600	4.95
Kochia, forage	520,000	0.61
Mountain mahogany, birchleaf	55,000	5.80
Mountain mahogany, true	59,000	5.42
Rabbitbrush, whitestem rubber	693,020	0.46
Sagebrush, basin big	2,576,000	0.12
Sagebrush, mountain big	1,924,000	0.16
Sagebrush, Wyoming big	2,466,000	0.13
Saltbush, fourwing	55,400	5.78
Winterfat	112,300	2.85

To assure that seeds from specific wildland locations are harvested and sold, regulatory agencies have established a seed certification program to inspect and verify the origin and sale of source-identified collections. This program complements the more traditional seed certification process (Young and others 1995).

Seeds of native species will vary a great deal in quality among collection sites and among years of collection (Toole 1940, 1941). Seed quality is affected by climatic conditions, insects, previous browsing, the timing of seed harvest, methods of collection, seed cleaning, and storage conditions. Seeds that ripen irregularly such as many berry crops are often harvested before the seeds have fully matured. Seeds of antelope bitterbrush, arrowleaf balsamroot, and Martin ceanothus are often damaged by insects (Ferguson and others 1963; Schopmeyer 1974b), and seedlots must be carefully inspected to assure that viable seeds are planted. The cleaning processes used to clean fruits of mountain mahogany, rabbitbrush, lomatium, and winterfat may damage the seed. Removing seed appendages from rabbitbrush or winterfat can reduce seedling establishment success (Simpson 1952; Stevens and others 1986). Seeds of fourwing saltbush, redstem ceanothus, and various other species are subject to insect damage during periods of storage.

To maintain viability, seeds should be stored under cool, dry conditions (Stein and others 1974). Some seeds, particularly forage kochia, must be dried to a specific moisture content of about 7 percent or seed viability declines rapidly.

Seed germination percentages do not always reveal quality of the seed. Seeds may germinate normally, but seedlings may not grow satisfactorily. Erratic performance of the seedlings may result from being damaged during cleaning, or because seeds were harvested before they were mature. Good seedling vigor is essential to survival of young plants. Tests are not currently available to fully discern the potential vigor of the seedlings. In general, larger seeds within a seedlot usually produce the most vigorous seedlings, germinate and emerge sooner, and often have higher germination (Green and Hansen 1969). However, attempting to separate and seed only large seeds is not considered a practical procedure for field plantings. It is important to select and use seeds from collection sites or varieties that consistently express good seedling vigor and germination features.

Seedlots often contain a high percentage of inert material. Seedlots of sagebrush, rabbitbrush, winterfat, aster, needlegrass, alder, and many other species cannot be easily cleaned to a high purity. Such species are normally processed by screening, chopping, or related treatments to condition the material to pass through most conventional seeders. Thus, seedlots are frequently sold and used that have only 10 to 20 percent purity. Seeds of these and other small-seeded species would have to be diluted with an inert carrier to facilitate seeding if the seed was cleaned to a purity approaching 40 percent.

Seed acquired from wildland collection sites should be submitted to certified seed laboratories for germination and purity tests. All seeds should be properly labeled with germination and purity percentages, date tested, and location of collection. As possible, information related to the conditions of the collection site should be made available by the vendor.

Seeding rates should be based upon the amount of pure live seed (PLS) (table 4) within the seedlot. Percent PLS is determined by:

$$\text{PLS} = \frac{\text{percent Germination} \times \text{percent Purity}}{100}$$

Selling seed on a PLS basis is much more practical than attempting to market bulk seedlots. Seed germination of individual seedlots is an important factor, and seedlots with unusually low percentages should be avoided. Seedlots with high germination percentages and low purity may still produce excellent healthy seedlings.

Table 4—Computing seeding rates and number of seeds sown.

Species	Mixture	PLS[a] desired	PLS of bulk seed	Bulk seed needed	Seeds per pound (PLS)	Seeds sown
	Percent	*lb/acre*	*Percent*	*lb/acre*	*No.*	*No./ft²*
Bluebunch wheatgrass	23	3.0	85	3.45	142,640	9.8
Western wheatgrass	19	2.5	72	2.95	115,000	6.6
Idaho fescue	15	2.0	88	2.24	497,370	22.8
Needlegrass	15	2.0	81	2.38	94,895	4.4
Arrowleaf balsamroot	15	2.0	85	2.30	55,245	2.5
Eaton penstemon	12	1.5	94	1.59	351,085	12.0
Mountain big sagebrush	2	0.2	.20	0.36	1,924,000	8.8
Total	100			15.27		66.9

[a]Pure live seed.

The condition of the seedlot is important to consider. Seedlots that contain considerable debris that will not flow through a seeder should be avoided. Extraneous material may be small enough to pass through a seeding mechanism, but too light in weight to flow under its own weight. Adding a carrier may be necessary to facilitate seeding. Seed cleaning processes may cut small stems and sticks into particles having rough and ragged ends. These small particles become clogged in the seedbox, drop tubes, and small gates of a seeder. Seed processing and cleaning should remove stems, weed seeds, leaves, and other debris that interfere with seeding, reduce bulk and handling, absorbs moisture, or causes heating in storage. Most seeds can be processed to facilitate seeding. Only a few lightweight, fluffy seedlots present unusual problems.

Determining Seeding Rates

Seeding rates for range and wildlife plantings have generally evolved through experience gained from seeding agronomic grasses. Studies in New Mexico by Springfield (1965), and in Idaho by Mueggler and Blaisdell (1955) reported that seeding crested wheatgrass at rates ranging from 2 to 6 lb per acre (2.3 to 6.8 kg/ha) produced nearly the same plant density, herbage yield, and plant sizes 5 to 6 years after seeding. However, this grass establishes very easily and seeding other perennial grasses at slightly higher rates varying between 5 to 12 lb per acre (5.6 to 13.5 kg/ha) has been recommended (Cook and others 1967; Hull and Holmgren 1964; Hull and Klomp 1967; Keller 1979; McGinnies 1960b; Plummer and others 1955; Reynolds and Springfield 1953).

Usually 8 to 16 lb per acre (9 to 18 kg/ha) for a total mixture is suggested for seeding game ranges to a diverse mixture of species. Actual volume depends on the individual sites and whether seeds are drilled or broadcast. As additional species are added to a seed mixture, the total weight of the mixture may or may not increase. If additional species of grasses are added to a mixture, the total amount sown is usually not increased. This is accomplished by reducing the amount of seed of each species in the mixture. If additional species of broadleaf forbs are added to a mixture, the total amount sown may or may not increase depending upon the other species in the mixture and the competitive problems that may occur. Sufficient seed of each species should be added to assure uniform and adequate distribution during planting.

As seeds of additional species are added to a mixture, the amounts of other species may often be reduced. However, the reduction is not necessarily proportional to the amounts added. Number of seeds per pound varies greatly between species (table 3). When seeds of a number of species are planted, usually more than one method of seeding is used. Some seeds may be broadcast sown, and others drilled or planted in separate furrows.

Total seed used is based upon the number of live seeds applied per square foot. Numbers vary somewhat, but approximately 20 live seeds per square foot (211 seeds/m^2) is recommended (Bryan and McMurphy 1968; Rechenthin and others 1965).

Light seeding rates normally require longer periods for complete stands to develop, whereas moderate rates produce a full stand in a shorter period (Mueggler and Blaisdell 1955). However, when weeds are not a problem, light seeding rates result in better recovery of native plants and a better chance for all species sown to establish. Higher seeding rates control weeds better (Hull and Klomp 1967), which is desirable since poor initial stands may not develop dominance if weeds exist (Launchbaugh and Owensby 1970). Hull and Holmgren (1964) concluded that irregular plant distribution and uneven grazing results from thin seedings. Hyder and Sneva (1963) reported that planting wheatgrass in rows not over 12 inches (30 cm) wide increased the proportion of vegetative shoots and palatability. Irregular plant spacings have been observed to be more conducive to the establishment of a greater number of species than close, uniform, row plantings.

When seeding grasses for range or pasture purposes, planting approximately 20 seeds per ft^2 (211/m^2) is an appropriate standard. However, species that establish and spread quickly by tillering, rhizome expansion, or natural seeding may be seeded at rates as low as 6 seeds per ft^2 (60/m^2) (Hughes and others 1962). Increasing the seeding rate for slower developing species and species producing weaker seedlings is appropriate (Launchbaugh and Owensby 1970).

Confining seeding rates to 20 seeds per ft^2 (211/m^2) for many seed mixtures is not always appropriate. Seed mixtures that contain small seeds of big sagebrush, Canada bluegrass, western yarrow, Pacific aster, or various species of penstemon will normally contain more than 20 seeds per ft^2 (211/m^2). These species have between 1 to 3 million seeds per lb (2.2 to 6.5 million/kg). Seeding just 1 pound of seed containing 2 million seeds per lb would result in nearly 46 seeds per ft^2 (485/m^2). It is often impractical to reduce seeding rates below 0.5 lb per acre (0.56 kg/ha) just to maintain a 20 seed per ft^2 (211/m^2) standard. It is difficult to uniformly spread very small amounts of seed in large-scale projects. Small amounts can be sown if a carrier is added to provide the volume necessary to handle and distribute the material. Adding small amounts of seed of certain species to a mixture with other species also provides a means of mixing, handling and dispensing the material.

Seeding rates should be based upon plant density and distribution patterns desired. When a number of species are sown, the distribution and density achieved are based upon survival of the seedlings. Usually a greater density of grasses and broadleaf herbs is desired than shrubs when mixed seedings are conducted. Often only one shrub may be required for each 100 sq ft (9.2/m^2), amounting to approximately 435 plants per acre (1,074/ha). The percent success of seed sown is often influenced by the species and amount of seed sown. Richardson and others (1986) reported that slightly more than 2,200 plants of mountain big sagebrush, 2,788 rubber rabbitbrush, and 1,040 antelope bitterbrush established per acre (5,436, 6,889, and 2,570/ha) when seeded as a mixture at 4 lb per acre (4.5 kg/ha) in southern Idaho. Shrub numbers dropped to 81 plants of mountain big sagebrush, 116 rubber rabbitbrush, and no antelope bitterbrush plants per acre (200, 287, 0/ha) when perennial grasses were seeded at 12 lb per acre (13.5 kg/ha) with the shrubs. Increasing the seeding rate of the shrubs to 20 lb per acre (22.5 kg/ha) and grass to 18 lb per acre (20.3 kg/ha) resulted in increased establishment of sagebrush and rabbitbrush seedlings, but no antelope bitterbrush seedlings survived.

Mueggler and Blaisdell (1955) reported that when crested wheatgrass was seeded alone, exceptionally heavy seeding rates did not cause stand failure from excessive competition among seedlings. Similar results have been obtained when individual native grasses and herbs are seeded as single species. However, when mixtures are seeded, increasing the seeding rate of individual species affects the survival of others sown. When aggressive grasses are seeded with broadleaf forbs or shrubs, the seeding rate of the grasses should not exceed 2 to 4 lb PLS per acre (2.25 to 4.5 kg/ha). Certain circumstances may alter this amount, but grass seed should be limited to assure survival of other species.

The seeding rate of alfalfa when sown with grasses in irrigated and nonirrigated pastures has usually been between 0.5 and 2 lb (PLS) per acre (0.56 to 2.25 kg/ha) (Allred 1966; Kilcher and Heinrichs 1968; Rumbaugh and others 1965). Seeding rangelands with as much as 5 lb per acre alfalfa (5.6 kg/ha) has resulted in excellent stands. Seeding rates of other broadleaf herbs are quite different from alfalfa. Small-seeded species such as western yarrow, Pacific aster, and Lewis flax can be seeded at much lower rates. However, higher rates are required to attain similar results for large-seeded species such as Utah sweetvetch, arrowleaf balsamroot, or silky lupine.

Results from seeding a single species indicate that increasing the seeding rate usually increases the number of seedlings that emerge, but reduces the number of plants established per 100 seeds sown (Cook and others 1967; Launchbaugh and Owensby 1970; McGinnies 1960b; Vallentine 1971). When mixtures are seeded, increasing the seeding rate will normally result in an increase in number of seedlings that emerge, but seedlings of certain species will survive better than others. For example, increasing the amount of Lewis flax, sulfur eriogonum, and alfalfa seeds sown usually results in a proportional increase in plants that establish and survive. In contrast, increases are less apparent for arrowleaf balsamroot and gooseberryleaf globemallow.

Determining Seeding Rates Based Upon Methods of Seeding—The amount of seed sown also depends, in part, on the planting methods and equipment used. Certain practices are more efficient than others. Approximately 50 to 75 percent more seed has been recommended when broadcast seeding is used compared with drilling (Cook 1966; Plummer and others 1955). However, evaluations of numerous aerial broadcasting and anchor chaining projects of pinyon-juniper sites in Utah have shown that an increase of about 20 percent is necessary for development of satisfactory stands. Aerial seeding usually distributes seeds very uniformly, and chaining provides adequate coverage. Unless broadcast seeds are covered or incorporated in the soil many do not germinate or become established. Broadcast seeding is not advisable unless some method of seed coverage is used. Increasing the seeding rate will not substitute for poor planting techniques. Drilling usually results in more uniform placement of the seed in the soil than broadcasting followed by harrowing or chaining. Seeds of certain species, particularly small seeds, establish better from shallow or surface placement, and broadcast planting followed by light harrowing provides an ideal seedbed for smaller seeds (table 5).

Seeding rates for mixed seedings can usually be reduced if the seedbox is partitioned into separate compartments, and seeds of similar sizes are grouped and seeded in separate rows from seeds with different sizes or shapes (Wiedemann 1975). If this is done, the seeding rates can be more precisely metered and more uniform distribution is also achieved. If planting depths can be separately adjusted for each furrow seeder, better seed placement will result and a higher percentage of the seed will establish. Various seeders, including drills and imprint planters, have multiple seedboxes and can simultaneously plant seeds of different species in separate rows and at different rates and depths.

Seeding grasses, broadleaf herbs, or shrub seeds in alternate or separate rows increases the chance of success as seedling competition is reduced (Hafenrichter and others 1968; Plummer and others 1968). Species mixtures seeded in alternate rows maintain their original composition better than when mixed in each row (Gomm 1964; McWilliams 1955). Seeding in alternate or separate rows also allows greater

Table 5—Pounds of seed per acre[a] required to seed one, five, and 10 seeds per linear foot (0.3 m) (drilled) or square foot (0.01 m^2) (broadcast).

Species	Number of seeds per linear foot		
	One seed	Five seeds	Ten seeds
	- - - - *lb Seed/Acre* - - - -		
Grasses			
Brome, smooth	0.32	1.6	3.2
Dropseed, sand	0.008	0.04	0.08
Fescue, hard sheep	0.08	0.40	0.8
Needlegrass, green	0.27	1.35	2.7
Orchardgrass	0.09	0.45	0.9
Ricegrass, Indian	0.27	1.35	2.7
Rye, mountain	0.77	3.85	7.7
Timothy	0.03	0.15	0.3
Wheatgrass, bluebunch	0.30	1.5	0.3
Wheatgrass, fairway crested	0.14	0.7	1.4
Wheatgrass, intermediate	0.50	2.5	5.0
Wheatgrass, pubescent	0.50	2.50	5.0
Wheatgrass, Siberian	0.20	1.0	2.0
Wheatgrass, slender	0.33	1.65	3.3
Wheatgrass, standard crested	0.23	1.15	2.3
Wheatgrass, tall	0.56	2.8	5.6
Wheatgrass, western	0.38	1.9	3.8
Wildrye, Great Basin	0.33	1.65	3.3
Wildrye, Russian	0.25	1.25	2.5
Forbs			
Alfalfa	0.20	1.0	2.0
Balsamroot, arrowleaf	0.77	3.85	7.7
Burnet, small	0.77	3.85	7.7
Flax, Lewis	0.16	0.8	1.6
Globemallow, gooseberryleaf	0.09	0.45	0.9
Goldeneye, showy	0.04	0.2	0.4
Lupine, mountain	3.45	17.25	34.5
Milkvetch, cicer	0.38	1.9	3.8
Penstemon, Palmer	0.07	0.35	0.7
Sainfoin, common	1.67	8.35	16.7
Sweetvetch, northern	1.30	6.5	13.0
Shrubs			
Bitterbrush, antelope	2.8	14.0	28.0
Ceanothus, redstem	0.37	1.85	3.7
Chokecherry, western	10.0	50.0	100.0
Cliffrose, Stansbury	0.68	3.4	6.8
Ephedra, green	1.75	8.75	17.5
Kochia, forage	0.08	0.4	0.8
Mountain mahogany, curlleaf	0.83	4.15	8.3
Mountain mahogany, true	0.71	3.55	7.1
Rabbitbrush, low mountain	0.06	0.3	0.6
Rabbitbrush, white rubber	0.06	0.3	0.6
Sagebrush, basin big	0.02	0.1	0.2
Sagebrush, black	0.05	0.25	0.5
Sagebrush, mountain big	0.02	0.1	0.2
Sagebrush, Wyoming big	0.02	0.1	0.2
Saltbush, fourwing	0.77	3.85	7.7
Serviceberry, Saskatoon	1.0	5.0	10.0
Winterfat	0.38	1.9	3.8

[a]Based on seeds per pound at 100 percent purity (table 1).

flexibility in spacing and seeding rates. Certain shrubs can be seeded separately from grasses, and a greater percent of the shrub seed sown will establish (fig. 10).

Various seed agitators and regulating mechanisms now exist that more uniformly plant seeds of irregular shape and size (Wiedemann 1983; Wiedemann and others 1979). Seed loss due to irregular plantings has been decreased with the use of new seeders, and seed is more efficiently planted.

Interseeding into existing stands is often employed to improve stand composition (Stevens 1985a,b). In addition, seeding some species in strips, rows, or selected spots is commonly done (Welty and others 1983). Species are often seeded using single row planters or Hansen Seed Dribblers mounted on wheeled tractors or track-driven “cats”. These seeders may be used to plant areas where broadcast or drill seeding is also being used. Seeding individual species using separate items of equipment can greatly reduce the amount of seed planted. Shrub seeds that are sown in furrows spaced 10 to 20 ft (3.1 to 6.1 m) apart often provide an acceptable cover, and subsequently furnish an adequate seed source for natural seeding. If furrows are spaced 10, 15, or 20 ft (3.07, 4.6, 6.14 m) apart, only 10, 6.7, and 5 percent of the total area is actually sown. Seeding rates and amount of seed sown at different row spacings are presented in tables 5 and 6.

Spot seeding is a practical method of seeding many species, particularly with highly expensive seed or species that may require specific seedbed conditions. Spot seeding following chaining on pinyon-juniper sites is a useful and successful practice. Certain browse seeds can be hand planted into the pits and depressions created where trees are uprooted. These depressions or catchment basins are favorable sites for seedling establishment.

Figure 10—Seeding of whitestem rubber rabbitbrush in alternate rows with fairway crested wheatgrass.

Table 6—Seeding requirements for some Intermountain shrubs. Shown are pounds of pure live seed required per acre, for four seeding rates, at each of four different row spacings.

			Number seeds per linear foot							
			Five				Ten			
			Row spacings ft							
	Purity/	No.	5	10	15	20	5	10	15	20
Species	germination	PLS per lb[a]	Amount of seed sown, PLS lbs per acre[b]							
	Percent									
Bitterbrush, antelope	95/90	15,370	2.83	1.42	1.0	0.71	5.67	2.84	1.98	1.42
Ceanothus, Martin	98/75	82,900	0.53	0.26	0.18	0.13	1.05	0.53	0.37	0.26
Ceanothus, redstem	98/85	131,860	0.33	0.17	0.12	0.09	0.66	0.33	0.23	0.17
Chokecherry, black	98/80	4,150	10.50	5.25	3.67	2.63	11.00	5.50	7.35	2.75
Cliffrose, Stansbury	95/85	64,615	0.67	0.34	0.24	0.17	1.34	0.67	0.47	0.34
Currant, golden	95/65	356,180	0.12	0.06	0.04	0.03	0.24	0.12	0.09	0.06
Elderberry, blue	95/50	216,770	0.21	0.11	0.07	0.06	0.42	0.21	0.14	0.11
Ephedra, green	95/85	24,955	1.75	0.88	0.61	0.44	3.50	1.75	1.22	0.88
Eriogonum, Wyeth	95/75	141,310	0.31	0.16	0.11	0.08	0.62	0.31	0.22	0.16
Mountain mahogany, curlleaf	90/80	51,865	0.84	0.42	0.29	0.21	1.68	0.84	0.59	0.42
Mountain mahogany, true	90/80	59,030	0.74	0.37	0.26	0.19	1.48	0.74	0.52	0.37
Rabbitbrush, whitestem rubber	15/75	693,220	0.06	0.03	0.02	0.01	0.12	0.06	0.04	0.03
Rose, Woods	95/70	45,300	0.96	0.48	0.34	0.24	1.92	0.96	0.67	0.48
Sagebrush, big basin	12/80	2,575,940	0.02	0.01	0.006	0.005	0.04	0.02	0.01	0.01
Sagebrush, black	12/80	907,200	0.05	0.03	0.02	0.01	0.10	0.05	0.03	0.02
Saltbush, fourwing	95/50	55,365	0.79	0.40	0.28	0.20	1.58	0.79	0.55	0.39
Serviceberry, Saskatoon	95/85	45,395	0.96	0.48	0.34	0.24	1.92	0.96	0.67	0.48
Shadscale	95/35	64,920	0.67	0.34	0.24	0.17	1.34	0.67	0.47	0.34
Snowberry, mountain	95/80	54,065	0.81	0.41	0.28	0.21	1.62	0.81	0.56	0.41
Sumac, smooth	94/40	62,430	0.70	0.35	0.24	0.18	1.40	0.70	0.49	0.35
Winterfat	50/85	112,270	0.39	0.20	0.14	0.10	0.78	0.39	0.27	0.20

			Number seeds per linear foot							
			Fifteen				Twenty			
			Row spacings ft							
	Purity/	No.	5	10	15	20	5	10	15	20
Species	germination	PLS per lb[a]	Amount of seed sown, PLS lbs per acre[b]							
	Percent									
Bitterbrush, antelope	95/90	15,370	8.50	4.25	2.98	2.13	11.34	5.67	3.97	2.83
Ceanothus, Martin	98/75	82,900	1.58	0.79	0.55	0.39	2.10	1.05	0.74	0.52
Ceanothus, redstem	98/85	131,860	1.0	0.5	0.35	0.25	1.32	0.66	0.46	0.33
Chokecherry, black	98/80	4,150	31.49	15.75	11.00	7.87	41.98	20.99	14.69	10.49
Cliffrose, Stansbury	95/85	64,615	2.02	1.0	0.71	0.50	2.68	1.34	0.94	0.67
Currant, golden	95/65	356,180	0.37	0.18	0.12	0.09	0.50	0.25	0.17	0.12
Elderberry, blue	95/50	216,770	0.60	0.30	0.21	0.15	0.80	0.40	0.28	0.20
Ephedra, green	95/85	24,955	5.24	2.62	1.83	1.31	7.00	3.50	2.44	1.75
Eriogonum, Wyeth	95/75	141,310	0.93	0.46	0.32	0.23	1.24	0.62	0.43	0.31
Mountain mahogany, curlleaf	90/80	51,865	2.52	1.26	0.88	0.63	3.36	1.68	1.18	0.84
Mountain mahogany, true	90/80	59,030	2.21	1.10	0.78	0.55	2.96	1.48	1.03	0.74
Rabbitbrush, whitestem rubber	15/75	693,220	0.19	0.09	0.07	0.05	0.24	0.12	0.09	0.06
Rose, Woods	95/70	45,300	2.89	1.44	1.01	0.72	3.84	1.92	1.35	0.96
Sagebrush, basin big	12/80	2,575,940	0.05	0.03	0.02	0.01	0.08	0.04	0.02	0.01
Sagebrush, black	12/80	907,200	0.14	0.07	0.05	0.04	0.20	0.10	0.07	0.05
Saltbush, fourwing	95/50	55,365	2.36	1.18	0.83	0.59	3.15	1.57	1.10	0.78
Serviceberry, Saskatoon	95/85	45,395	2.88	1.44	1.01	0.72	3.84	1.92	1.34	0.96
Shadscale	95/35	64,920	2.01	1.00	0.70	0.50	2.68	1.34	0.94	0.67
Snowberry, mountain	95/80	54,065	2.42	1.21	0.85	0.60	3.22	1.61	1.13	0.81
Sumac, smooth	94/40	62,430	2.09	1.04	0.73	0.52	2.80	1.40	0.98	0.70
Winterfat	50/85	112,270	1.16	0.58	0.41	0.29	1.55	0.78	0.54	0.39

[a]Number of PLS/lb is determined on the number of pure live seeds per pound.
[b]Amount of seed sown is computed in pounds of pure live seed.

Spot seeding also allows for more careful control of the number of seeds sown. Ferguson and Basile (1967) reported that a lone seedling of antelope bitterbrush is less likely to survive than if a group of seedlings emerge together. Seedlings grouped together provide mutual protection from heat and aid in breaking of a soil crust during emergence. Evans and others (1983) reported rodent depredation of planted antelope bitterbrush seeds is reduced if seeds are not placed on a continuous, uniform row. Also, placing seeds at different depths in the soil and seeding fewer seeds together in a spot reduced the chance of rodents being able to locate and destroy the seeds.

Compensating for Seed and Seedling Losses—A high percentage of seeds sown fail to emerge or establish. Seed and seedling losses normally result from poor seedbed conditions, unfavorable moisture conditions, frost, animal depredation, damage by insects and disease, and competition. Less than 10 percent of viable wheatgrass seeds sown produce seedlings (Cook and others 1967). Luke and Monsen (1984) reported from plantings in southern Wyoming that seedling establishment of different species of shrubs varied between 0.01 to 3.30 percent of all seed planted.

Plantings of fourwing saltbush in central Nevada have resulted in established plants from over 10 percent of the seed sown (Monsen and Richardson 1984). Big sagebrush and rubber rabbitbrush exhibited excellent ability to establish amid considerable competition, but less than 3.5 percent of the seed sown for each of these two species produced seedlings. Seedling density is apparently regulated by site factors, and overseeding is not necessary.

Rodents feed on the seed of numerous species (Everett and Monsen 1990). These animals frequently destroy nearly entire plantings by foraging upon the seeds and seedlings (Nelson and others 1970; Nord 1965; Sullivan and Sullivan 1982). Although rodents consume the majority of seeds produced each year, their caches are also instrumental in plant recruitment (McAdoo and others 1983; West 1968). Rodent caches benefit species that respond favorably to grouped seedings (Ferguson and Basile 1967).

Deer mice eat or dig up seed of commonly seeded species equal to approximately one-third of their body weight daily (Everett and others 1978b). The amount of seed taken in the field is proportional to the amount available (Sullivan 1978). Thus, animals quickly gather and use planted seeds (fig. 11).

Rodents apparently operate under an “optimal factor” strategy where they harvest seed from dense patches or clumps rather than dispersed seeds (Price and Jenkins 1986; Pyke and others 1977). However, seeds broadcast on the soil surface are nearly entirely consumed even though located in a random pattern (Nelson and others 1970). Buried seeds are less preferred because of the energy spent in digging (Price and Jenkins 1986). Rodent mining for seeds has been reported to occur if seeds are concentrated in rows (Nord 1965), and high losses can result if seeds are placed at uniform depths. Drilling may place seeds in fixed horizontal and vertical planes. Therefore, if seeds can be randomly located in the soil, losses to rodents can be reduced. Rodents favor large seeds over small seeds (Everett and others 1978b; Howard 1950; Standley 1988), because they are more easily located (Price and Jenkins 1986). Large seeds may be preferred as the relative number required to meet daily energy demands is less (Kauffman and Collier 1981; Reichman 1977).

Figure 11—Mouse excavation of planted antelope bitterbrush seed.

Rodents are able to locate buried seeds by olfactory search image (Sullivan 1979). The size and planting depth of the seed affects detection (Reichman and Oberstein 1977). Evans and others (1983) found that seeds of antelope bitterbrush planted in groups of 2, 10, 45, or 100 were much more easily located and consumed by rodents than if one seed was planted per spot. Also, rodents never dug up one bitterbrush seed, but if two were planted together, over 75 percent were removed. Over 98 percent were taken if more than two were planted. Rodents were able to detect most bitterbrush seeds if planted at normal seeding depths. Planting fewer seeds per spot or randomly placing desirable seeds in the soil are procedures that can be used to lessen losses to rodents.

Although sacrifice foods have not been fully tested as a means to protect range seedings, laboratory and field trials suggest millet, sunflower, and rolled barley as potential sacrifice foods (Everett and Monsen 1990; Kelrick and MacMahon 1985; Kelrick and others 1986). Feeding sunflower seeds as sacrifice food to rodents increased conifer survival from 5 to 70 percent (Sullivan 1979).

Various repellents have been applied to seeds to reduce animal depredation. Endrin has been the most successful (Plummer and others 1970b), but use of this compound has been prohibited because of environmental concerns. Everett and Stevens (1981) found that alpha-naphthylthiourea (ANTU) reduced deer mice consumption of bitterbrush seed more than other chemicals tested. Passof (1974) reported that the chemical effectively doubled seedling stocking rates of conifers.

Late fall or winter seedings are recommended to reduce the loss of seeds to rodents. At this time rodent activity has declined. Rodent populations are at their lowest point in the early spring, but spring seedings are not the most desirable.

Modification of Seeding Rates—Seeding rates and planting procedures can be modified when necessary. In high risk areas where soil stability, aesthetics, or habitat are of prime concern, increasing seeding rates and intensifying planting may be justified. Using high quality seed, and delaying planting until conditions are ideal for seeding are useful practices that can increase success (Phillips 1970).

Using high seeding rates and planting techniques that may be less than optimal may be justified in certain situations. For example, aerial seeding of big sagebrush, winterfat, and rubber rabbitbrush followed by chaining or harrowing may not produce as many seedlings as using a modified ground seeder. However, satisfactory stands can be achieved, and savings in seeding costs more than compensate for losses of seed by broadcast seeding.

Low seeding rates can also be justified at some locations. If weed invasion is not a problem, some pinyon-juniper chainings can be lightly seeded to allow more complete recovery of desirable species. Although the planting sites may initially appear weedy or support a weak ground cover, the ultimate plant community usually forms a diverse, acceptable cover.

Effects of Seed Characteristics on Seeding Rates—Seed size occurring in different seedlots of many species may vary enough to require adjustments in seeding. Differences in seed size of fourwing saltbush (Foiles 1974), black chokecherry (Grisez 1974), curlleaf mountain mahogany (Deitschman and others 1974a), and bottlebrush squirreltail necessitate considerable adjustment in computing seeding rates and operation of seeding equipment.

The percent moisture in seedlots of fourwing saltbush, winterfat, Apache plume, and vegetable-oyster salsify can also affect the amount of seed needed. Also, the amount, size, and shape of debris in seedlots can determine the choice of equipment, planting methods, and seeding rates used. Seedlots of Apache plume, Rocky Mountain maple, and western virginsbower are difficult to clean, and the methods used to collect and clean the seed often determine the methods that can be used in planting.

Seeds extracted from berries or dry fruits sometime have portions of the fruit attached to the seed. The rough surface of the attached material reduces the flow of the seed through most seeders. Seed regulatory gates or control openings must be opened wide to accommodate movement of the seed through the seedbox and dispensing mechanisms. In doing so, seeding rates become difficult to regulate. Such seed must often be diluted to prevent overseeding.

Seeds of extremely different size, shape, density, and purity often cannot be seeded together without modification of planting equipment. Seeds of big sagebrush, rubber rabbitbrush, and winterfat are commonly seeded with other species and this may necessitate improvisations to permit seeding. Additions of very small or extremely large seeds to a mixture can be accommodated by using materials to reduce planting rates. Some seeding equipment, particularly picker-type seeders or fluted seeders and are designed to plant irregular sized and mixed seedlots. However, trashy seedlots are not easily planted. In most situations extremely trashy seedlots must be planted separately with special equipment. Spending time to clean seed to a desired condition is usually well worthwhile. Some time should be spent calibrating the selected seed dispensing mechanism to achieve the rate of seeding desired.

Treating Seeds to Improve Establishment

Preconditioning Seeds—Various treatments have been employed to pretreat seeds that are difficult to germinate. Seeds with thick, impermeable seedcoats or structures can be mechanically fractured to promote germination (Stein and others 1974). Hammermilling utricles of fourwing saltbush and shadscale fractures the tough wall and allows seeds to germinate quickly and more uniformly. Hard seedcoats or fruit structures can also be treated with sulfuric acid (Brinkman 1974g; Krugman and others 1974), but this treatment is difficult to apply, particularly to large seedlots.

Pretreating some seeds with various chemicals can relieve dormancy and allow seeds to germinate. Antelope bitterbrush and Stansbury cliffrose are two species that respond to treatment with hydrogen peroxide or thiourea (Everett and Meeuwig 1975; Young and Evans 1983). Breaking seed dormancy with chemical treatment facilitates seeding in the spring. However, seeding success is not as good as with fall seeding, and this practice is not usually recommended.

Priming seeds to hasten germination is a technique that appears practical to improve seedling establishment (Bleak and Keller 1972) particularly when seeding in semiarid communities. Hardegree and Emmerich (1992) reported seed priming can be used to regulate seed germination of perennial grasses and enhance seedling establishment when seeded in areas occupied by cheatgrass.

Seed processing—Improving seed cleaning and seeding practices has significantly increased planting success. Removing fruit and floral structures by improved cleaning techniques greatly enhances seeding and helps ensure that seeds are correctly placed in the soil. However, removal of tissue attached to seeds of rabbitbrush and winterfat can reduce seedling establishment (Booth and Schuman 1983; Stevens and others 1986). Slight heating of seeds of Utah sweetvetch by grinding to open or remove the pod is very damaging. In this case, the seeds are not visually damaged, but germination is greatly reduced. Planting techniques and equipment have been developed to plant seedlots having trashy, lightweight, and fluffy seeds (Carlton and Bouse 1983; Hardcastle 1983; Stevens and others 1981b; Weidemann 1983). These advances have reduced cleaning and conditioning processes that often damage some seeds. Seed cleaning techniques have also been devised to condition seeds of sagebrush, alder, forage kochia, buckwheat, aster, and numerous other species without damage to the seed (Dewald and others 1983).

Seed inoculation—Seeds of all legumes should be treated with a commercial inoculate prior to planting. Lowther and others (1987) reported strains of rhizobia have limited distribution in the Intermountain West and those present have low nitrogen fixation capabilities. Thus, strains of the rhizobia specific for the legume being planted should be used. Pretreated seed can be purchased from most vendors. Strains of adapted inocula are available for some native legumes including Utah sweetvetch (Ford 1988).

At present, 162 species in 19 genera in 7 families of woody plants are known to form actinomycete-type root nodules (Bond 1976; Heisey and others 1980; Righetti and Munns 1980). Certain species of western shrubs of the Rose family function as symbiotic nitrogen fixers (Klemmedson 1979; Lepper and Fleschner 1977; Vlamis and others 1964; Wagle and Vlamis 1961). Nelson (1983) reported that actinorhizal root nodulation occurs with Stansbury cliffrose, desert and antelope bitterbrush, and curlleaf mountain mahogany, but procedures to inoculate the seeds have not been developed (Becking 1977; Nelson and Schuttler 1984).

Seed pelleting—Various methods have been tried to improve success from broadcast seedings. Techniques have been employed to substitute for harrowing, dragging, or chaining to eliminate the costs associated with seed coverage. Pelleting seed has been extensively tested for range, wildlife, and forestry seedings, but plantings have not been very successful (Hull and others 1963). Pelleted seeds require seed coverage or creation of a seedbed as does nonpelleted seed (Chadwick and others 1969). Seeds that establish from surface or shallow planting depths are best adapted to this method of seeding.

Monsen and Pellant (1989) reported that pellet seeding of winterfat significantly aided in aerial distribution of this lightweight seed. Seedlings established well from this method of planting, but success was not an improvement over broadcasting nonpelleted seed. Although pelleting of lightweight, trashy seed can enhance the flow and distribution of the seed through conventional drills and aerial seeders, pelleting is a difficult and expensive process. Pelleting does not overcome problems created by small sticks or other debris that cause material to cluster or lodge in the seeder.

Increasing the seeding rate of pelleted seed has not improved seedling establishment (Bleak and Hull 1958; Hull 1959) and no improvement in rodent deterrence has been detected with treated seed. Application of fungicides has been proposed as an added benefit with pelleted seed, but results have not been conclusive. Also the costs of pelleting, and the added shipping and handling fees are very high (Chadwick and others 1969).

Treating seeds to control pathogens—Treating seeds and soil to prevent damage by pathogens may be beneficial, but it is not widely done in range or wildlife seedings. Seed collected from wildland stands is often infested with seedborne pathogens (James 1985; James and Genz 1981), and various treatments have been tested to eliminate or reduce pathogenic organisms, particularly on conifer seeds (Barnett 1976; James and Genz 1981; Trappe 1961; Wenny and Dumroese 1987). Treatments have included the use of 100 percent ethanol or sodium hypochlorite with lowered pH, and soaking seeds in a 2 percent aqueous suspension of thiram for 24 hours (Maude and others 1969; Sauer and Burroughs 1986). Dodds and Roberts (1985) discuss the sterilization of seed using a 1 to 3 minute soak in a 70 percent ethanol solution, followed by a soak in sodium hypochlorite. Hot water treatments have also been employed without reducing seed germination (Baker 1962a,b), and the use of a microwave oven to heat water to the desired temperature (Lozano and others 1986).

Damping-off fungi are particularly damaging to antelope bitterbrush, winterfat, and fourwing saltbush seedings (Ferguson and Monsen 1974). Organisms can be transitted through ingestation of the seed or potting media. Treatment with a mixture of Benlate (methyl 1-[butylcarbamcyl] -2 benzimidazole-carbamate) and Dexon [p-dimethlamino] benzenediazo sodium sulfonate has been successful as a drench. Treatment of nursery beds using a soil drench (Pawuk and Barnett 1974) has been effective in controlling fusarium fungi that are responsible for seedling mortality (Landis 1976) due to damping-off and rootrot.

Pretreating seeds may be effective in reducing seed disease problems, but the use of disease-free seeds is preferable, whenever possible. Nelson (1984) cautions that fungicidal treatments to prevent seedling diseases often only suppress the pathogen which will later induce further disease. However, sufficient seed damage from pathogens has been observed in various wildland plantings to suggest that control measures would be beneficial to some species. Heavy losses occur with lupine, balsamroot, Utah sweetvetch, antelope bitterbrush, serviceberry, and blue elderberry. Seeds should be pretreated if disease problems are likely to be serious.

Seedbed Preparation and Seeding

An ideal seedbed for range or wildlife seedings: (1) is free of competitive weeds (seeds and plants) that may prevent establishment of seeded species; (2) has a friable structure that allows infiltration of moisture and does not puddle or become compacted by seeding equipment or rainfall; (3) can be easily worked to incorporate seed into the soil; (4) has a firm soil beneath the seeding depth; and (5) contains sufficient surface mulch to prevent rapid drying. The principal purpose of seedbed preparation is to control weeds and condition the soil for seeding. A minimum number of tillage or treatment operations are used on most wildland sites. Access is often limited; debris, rock, or terrain limit the techniques that can be used. Often only one or two techniques are used to control weeds, prepare, and seed a site.

Control of Competition

Seedings have been most successful when existing competition has been eliminated (Cox and others 1986; Holmgren 1956; Hubbard and Sanderson 1961). Most control measures are designed to remove existing vegetation and seedbanks. These procedures are particularly important in semiarid and arid regions where moisture is critical to seedling establishment (Vallentine 1989), and in vegetative types where competition is severe. Adequate weed control is usually difficult to accomplish, particularly on sites infested with annuals (Plummer and others 1955).

Weed control or reduction of competition is necessary to (1) allow seeded species to establish; (2) release existing, but suppressed desirable plants; and (3) allow the spread of native and seeded species. To facilitate seeding, weed control measures are necessary for at least one season and sometimes for 1 or 2 years thereafter.

Figure 12—Well designed pinyon-juniper chaining. Allowances given for aesthetics, thermal, escape and travel cover, and sufficient edge effect.

Control measures do not always require complete elimination of all plants (fig. 12). Chaining of pinyon-juniper stands, dense patches of oakbrush, or thick stands of big sagebrush usually leave considerable vegetation, but the overstory plants are suppressed and seeded species are able to establish (Aro 1971; Davis 1987; Plummer and others 1968). Plant control measures are most critical in areas receiving limited rainfall (Houston 1957). Complete elimination of black greasewood or low rabbitbrush is not as critical if normal amounts of moisture are received following treatment. These plants are not overly competitive and some can be left in place. However, rainfall is too often unpredictable and leaving a high number of plants in place is risky.

Cook (1966) reported that complete removal of brush on low foothill ranges in the Intermountain area allowed seeded species to reach maturity in 5 years. Seeded stands required 10 to 11 years to attain full potential when brush control was only 60 to 80 percent. The time required for seeded stands to attain maturity is not as critical as the chance of having seedlings fail to establish. Control measures should be designed to assure stand establishment. Maturation and productivity levels may be delayed but can be tolerated.

Planting sites that are infested with annual weeds usually requires complete weed control (fig. 13). Cheatgrass, medusahead, and most summer annuals offer serious competition to seeded species (Evans and Young 1978; Hull 1963a; Hull and Pechanec 1947; Robertson and Pearse 1945; Rummell 1964). Decreasing the density of annuals does not always reduce the deleterious competitive effects of the remaining plants.

Nearly complete removal of all annual plants and seed is necessary to establish new seedlings of most seeded species (Hulbert 1955; Robertson and Pearse 1945; Young and others 1969a). Annual weeds compete directly with natural seedlings of Stansbury cliffrose (Cline 1960), and shrub seedlings succumb in the late spring and early summer as soil moisture is depleted. Summer annuals are also highly competitive (Haas and others 1962), particularly when mixed stands of Russian thistle and pepperweed exist with annual grasses.

'Hycrest' crested wheatgrass (Asay and Knowles 1985a,b), forage kochia (Monsen and Turnipseed 1990), bottlebrush squirreltail, and 'Appar' Lewis flax are species able to compete as seedlings with a moderate population of annual weeds. However, direct seeding into unprepared weedy seedbeds should be avoided. In general, shrub seedings are less competitive with annual grasses than are most commonly seeded herbs (Hubbard 1964). Seedlings of antelope bitterbrush are better able to compete with summer annuals than with cheatgrass (Holmgren 1956). Monsen and Pellant (1989) found that seedlings of winterfat competed better with perennial native grasses than with cheatgrass. If cheatgrass cover approached 10 to 15 percent, few winterfat seedlings survived.

Giunta and others (1975) reported differences in establishment success among several shrub species seeded on a pinyon-juniper site in central Utah, when various size clearings were used to reduce cheatgrass competition. Most shrub seedlings required clearings that were 30 and 40 inches (76 to 102 cm) wide to establish (fig. 13). Holmgren (1956) reported similar sized openings were required in cheatgrass-infested ranges in Idaho to assure the establishment of seeded antelope bitterbrush. From studies in California (Hubbard 1964) and Idaho (Medin and Ferguson 1980) clearings of 30 to 40 inches (76 to 102 cm) were recommended for antelope bitterbrush seedling establishment.

In more mesic sites where annual rainfall exceeds 14 to 16 inches (360 to 410 mm), herb seedings are usually more successful, and weed control is not as difficult. However, even here shrub species cannot be established without seedbed preparation. Mountain snowberry, Saskatoon serviceberry, Martin ceanothus, and true mountain mahogany are commonly seeded in these sites, but are sensitive to the competitive effects of associated herbs. Weedy or competitive plants must be controlled for 1 to 3 years to allow seedlings time to establish.

Dense stands of highly competitive perennial sod and annual weeds occur on high summer ranges and require control measures (McGinnies 1968). Treatment of cluster tarweed (Hull 1971b) is essential for seedling establishment of seeded species. Seeding of inland saltgrass and disturbed meadow sites also requires extensive weed control.

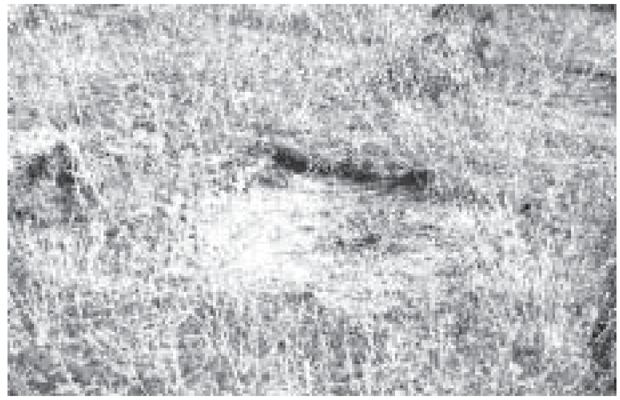

Figure 13—Antelope bitterbrush seeded into clearings where competition has been removed.

Riparian disturbances often require considerable control measures to eliminate persistent and competitive weeds (Platts and others 1987). Disturbances are often occupied by rhizomatous sod and root-proliferating noxious weeds. These plants must be eliminated or dramatically reduced. Treatments such as deep plowing or disking may not kill the plants without repeated treatments (Platts and others 1987; Plummer and others 1968). These measures leave the surface subject to serious erosion from spring runoff and storm events. However, such extensive control measures are necessary to seed many sites (Neiland and others 1981).

Conservation of Moisture

Site preparation treatments should be designed to conserve and aid in storage of soil moisture. Most mechanical practices—plowing, railing, disking—tend to dry the soil surface, and should be done when moisture loss is kept at a minimum.

The most practical means of providing the maximum soil moisture to the seedbed is to treat sites at the right season. Site preparation and seeding should be conducted prior to the season when most precipitation is received. In most situations, late fall treatments are most successful. Disturbance to the soil can reduce infiltration and cause crusting and moisture loss. Disturbances should be limited in both seedbed preparation and seeding. Hyder and others (1955) found that rolling loose seedbeds improved seed placement and seedling emergence. Rolling, after broadcast seeding, was also a reliable method of covering seed and firming the seedbed, but rolling can also compact some soils, reducing seedling emergence.

Within the Intermountain area, seeding and weed control conducted in the fall allows spring-germinating species a better opportunity to use winter moisture stored in the soil. Stored moisture, coupled with spring rainstorms, provides the most favorable conditions for seedling establishment.

Fall or spring treatment of annual weeds, particularly cheatgrass, is helpful in eliminating annual growth (Klomp and Hull 1972). Treatments must be conducted after cheatgrass plants have germinated and emerged (Evans and Young 1978; Plummer and others 1968; Young and others 1969a).

Weed seeds normally are not eliminated unless the soil is deeply plowed and seeds are planted too deep to emerge. Light or shallow cultivation in the spring or fall can normally kill small seedlings (Bement and others 1965; McGinnies 1968).

Summer fallowing can be used to control plant growth and prevent the development of a seed crop (Harris and others 1972; Hart and Dean 1986). Summer fallowing is a useful technique to conserve soil moisture in areas of low annual rainfall, but fallowing practices are often quite expensive. Fallowing over a 1- to 2-year period is often necessary to control sod in mountain meadows.

Pitting, trenching, deep-furrow drilling, and creation of catchment basins have been used to intercept and accumulate moisture near the seedbed (Barnes 1952; Branson and others 1966; Hubbard and Smoliak 1953). Chaining also creates pits and small depressions, especially in areas where trees or large shrubs are uprooted (fig. 14). These spots also collect additional soil moisture that aids seedling establishment.

Treating soils that are wet can cause compaction and crusting. This reduces infiltration and may interfere with seedling emergence. On the other hand, treating sites when the surfaces are dry and loose can cause serious wind erosion. Such sites should not be left barren for long periods. Loose soil surfaces also dry rapidly, and site preparation treatments that leave a protective surface mulch should be used to conserve moisture (Hyder and Bement 1969).

Maintaining surface mulch and a standing crop to protect the soil surface improves seedling establishment (Malakouti and others 1978). Most planting sites contain some surface litter or mulch. This material should be kept in place, if possible, to lessen surface evaporation, provide protection to small seedlings, and reduce soil crusting (Herbel and others 1973). Mulch is particularly important for soils that dry rapidly, and may be subjected to fluctuating temperatures.

Deep furrow drilling using 12 to 16 inch (30 to 41 cm) row spacings has been a method used to concentrate soil moisture and improve seedling density (Anderson and others 1953; Artz and others 1970; Fisser and others 1974; Neff 1973; Wight and White 1974). Deep furrows have been reported to increase soil moisture during the period of spring germination by an average of 50 percent and sometimes up to 100 percent (McGinnies 1959). The deep furrows reduce soil moisture loss from evaporation, allow seedlings to use deeper stored moisture, and reduce temperatures near the seedling (McGinnies 1959). Deep furrow drilling should not be done when soils are dry, as sloughing normally occurs, causing seeds to be buried too deep.

Figure 14—Chaining can create excellent seedbeds, pits, and small depressions.

Entrapment of winter snow cover is essential to seedling establishment of many small-seeded, surface germinators. Meyer and others (1990a) reported that entrapment of winter snow on the planting site until the time of seed germination in the spring resulted in a significant increase of sagebrush seedlings from plantings in Idaho, Nevada, Montana, and Wyoming. Entrapment of snow by standing plants, particularly shrubs, is important to natural seedling establishment in arid and semiarid sagebrush communities of the Intermountain area. Maintaining some erect or standing plants can improve the soil moisture for new seedlings. Downed pinyon and juniper trees resulting from chaining trap snow and greatly improve seedling establishment in the affected areas. The tree litter remains effective for over 25 years.

Seedbed Firmness

Most undisturbed seedbeds are loose enough to be drill-seeded or seeds can be incorporated in the soil by chaining or harrowing. Sites that have been plowed or disked may require mechanical compaction to reduce moisture loss (Hyder and others 1961) and the problem of seeding too deep. Loose soil surfaces normally result in seeds being planted too deep and at irregular depths (Hyder and others 1955). Also, loose soil has poor moisture-holding capacity (Vallentine 1989). In contrast, firm seedbeds retain moisture near the seed zone and are much easier to plant at the desired depth. A loose or friable soil with an underlying firm soil is ideal for seeding. These surfaces are easy to plant at the proper depth.

Figure 15—Result of aerial seeding forbs, grass, and shrubs on top of snow.

Most drill seeders are equipped with packer wheels to compact the seeded furrow and lessen the depth of the soil overlying the seed. Rollers and other compaction equipment are available to pack or compress loose soils prior to seeding (Anderson and others 1953; Hyder and others 1955; Hyder and others 1961). Rolling or compaction before drilling allows for better seed placement (Hyder and others 1961). Cultipacker, roller type, or press seeders can be used to seed loose surfaces (Anderson and others 1953; Booster 1961; Richardson and others 1986). These seeders do not plant at depths exceeding 0.5 to 1.5 inches (1.3 to 3.8 cm). Depth bands and other modifications are used on many conventional drills to aid in suspending or preventing the disk from digging and planting too deep (McGinnies 1962). Hydraulically supported furrow openers and no-till seeders are also designed to control seed placement.

Offset furrow openers, or disks, are used to cut into dense litter and hard surfaces (Asher and Eckert 1973). Front-mounted rippers and no-till seeders are designed to plant firm seedbeds. Anchor chain modifications, pipe harrows, and chain harrows are effective implements used to seed and prepare firm or hard surfaces (further information related to the function of seeders is presented in chapter 9).

Seeding—Seeding is normally intergrated with the seedbed preparation. Often, chaining or drilling accomplishes both practices. To be successful, both practices must be conducted during the appropriate season or period. Seedbed preparation and seeding may be completed in the fall or early winter. During the interval between seeding and seedling emergence, the seedbed may be altered. Soil sloughing may bury some seeds too deep, or wind erosion can expose planted seeds. Dry, loose seedbeds can be expected to settle, which may result in satisfactory or unsatisfactory stands depending on the methods used in planting.

Planting Season

Fall or early winter seeding is necessary to provide seed stratification for many species (fig. 15). Most native shrub seeds require a cold, moist period to adequately overcome embryo dormancy (Shopmeyer 1974b). Seed germination may not occur until after stratification of 100 to 150 days for some species. Prestratified seed is frequently spring planted at nurseries, but gauging the stratification period to coincide with spring weather conditions is extremely hazardous. Pretreating seeds of antelope bitterbrush and a few other shrub species with hydrogen peroxide or thiourea can induce germination, but is not a satisfactory means of seeding large projects (Alexander and others 1987; Everett and Meeuwig 1975; McConnell 1960; Neal and Sanderson 1975; Pearson 1957; Young and Evans 1983). Different seedlots of antelope bitterbrush respond differently to the chemicals; some germinate quickly and uniformly and others do not. Spring plantings of naturally dormant seeds should be avoided.

Seeds of alfalfa and certain collections of winterfat and fourwing saltbush and many commonly seeded grass species are nondormant, and may be spring sown at certain locations. However, fall seedings generally provide more favorable stands of most species particularly under arid situations (Cook and others 1967; Plummer and others 1968). Alfalfa seeds that are fall sown often germinate in the early spring and many are killed by frost. Spring planting in early April, on a fall-prepared seedbed, usually reduces the problem. Spring planting may also reduce seedling losses to frost for some ecotypes of fourwing saltbush and winterfat. Seedlings of most grasses are quite frost tolerant, and stands normally are not lost to spring frosts.

Recent studies have demonstrated considerable variability in seed dormancy and germination requirements among ecotypes of different native species (Kelsey 1986; Kitchen 1988; Meyer and Monsen 1990; Shaw and Haferkamp 1990). Plantings of mountain big sagebrush and rubber rabbitbrush seed obtained from areas having relatively warm winters show different germination and emergence responses from collections acquired from cold winter locations (Meyer and Monsen 1990). Seeds of big sagebrush and rabbitbrush collected from areas with warm climates did not survive well from fall plantings in more northern regions. Collections from warm climates that were fall sown germinated quickly, usually in the late fall and winter, but were unable to survive beneath the snow. Germination requirements undoubtedly vary for many species, seedlots, or ecotypes, and these requirements should be understood before extensive seedings are made.

Vallentine (1989) concluded that range seedings should be made prior to the period of longest favorable moisture conditions. Within the Intermountain Region between 45 to 65 percent of the annual precipitation is received in the winter months. Rapid drying normally occurs following germination and seedling emergence in the spring. At most elevations late fall or early winter seeding is recommended. Seeding should be delayed long enough in the fall to prevent germination until the following spring (Gates 1968; Harris and others 1972; Plummer and others 1968; Vallentine and others 1963). Seeding early in the fall can be successful if sufficient moisture is available to germinate and maintain seedlings until cold temperatures arrive. Generally, sufficient soil moisture is not maintained for the entire period, and seedlings often succumb.

Jordan (1983) concludes that sites seeded in the fall to cool-season species should receive on the average 3.5 inches (89 mm) of precipitation through the months of November, December, January, and February. The average annual precipitation should be a least 10 inches (250 mm).

In the Southwest and the southern portions of the Intermountain Region where summer rains are common, spring seeding is advised for species having nondormant seed. Jordan (1981) recommended that warm-season species be seeded in the spring. Ideally, sites seeded in the late spring to either warm- or cool-season species should receive an average of 5.0 inches (127 mm) of moisture through July, August, and September. The average annual precipitation should be at least 11 inches (280 mm).

With respect to precipitation, Jordan (1983) reported that average annual precipitation values are often used to characterize range sites, but they are not adequate to describe the potential for reseeding. He developed a predictive model to determine the potential of a site for seeding based on precipitation, the arid or semiarid boundary, and the average annual temperature. In addition, the soil texture and water holding capacity of the soil is used to determine the availability of stored moisture. The predictive model developed by Jordan has not been widely applied to the germination and establishment of all species normally seeded in the Intermountain area, but it appears useful in defining areas that may or may not be seeded with success.

Fall seedings are more reliable for low valley and foothill communities where the annual precipitation would be less than 12 to 14 inches (300 to 260 mm). These sites normally dry quite rapidly in the spring and are subjected to a long, dry summer. Slow developing seedlings are often too small and weak to survive a dry summer period. Seeding in the spring on a fall-prepared seedbed is most successful if planting occurs early in the season. However, soils may be too wet and muddy to permit early spring seeding. If sites are allowed to dry, additional rain will be needed to germinate and maintain the seedlings. Usually, only a short period exists in the spring when conditions favor seeding (Evans and Young 1987a). Attempting to seed large areas in the spring is therefore, often impractical.

Considerable fluctuation occurs in both temperatures and soil moisture of the seedbed in the spring. Vallentine (1989) reported wet periods may last only 2 days, but seeds of most grasses that do not germinate are able to survive. If the wetting period lasts 5 days or longer, most seeds germinate and seedlings are able to survive subsequent drought periods of 5 to 7 days. Wester and Dahl (1983) reporting on studies in west Texas, concluded that alfalfa requires at least 0.4 inches (10 mm) of moisture at 75 °F (24 °C) to give high germination. Metabolic processes were initiated with only 0.2 inches (5 mm) of moisture, but seeds dried rapidly enough to halt germination before seed energy was spent if no additional moisture was received. Alfalfa seeds germinated and emerged in 3 days, and seedlings were able to survive 7 to 9 days if watered each of 2 days with 0.4 inches (10 mm) of moisture. Because alfalfa emerges so quickly, follow-up rain is needed sooner than for most grasses. Allen and others (1994) reported that seeds of some species may be able to accumulate germination events across periods interspaced with drying, and that continuous moisture is not necessary to sustain germinating seeds. Evans and Young (1987a,b) studying soil moisture conditions in arid regions of the West, found that soil moisture in the first centimeter of soil may decrease to –1.5 MPA and below in less than a week. Natural soil moisture depletion often coincides with the period of active seedling emergence.

Most seeds are conditioned to germinate in the spring after fall plantings. Fall sown seeds usually have imbibed necessary moisture, and exist in a moist medium under the snow. Seeds in this state can germinate quickly as the snow recedes. Seedlings that emerge first in the spring are better able to survive the dry summer period.

Seed Coverage and Planting Depths

Seed should be in firm contact with the soil to increase moisture availability (Stevens and Van Epps 1984), thus a majority of seeds require some amount of soil coverage (table 2). Soil can also act as an anchor to hold or maintain seed in a proper position, especially seeds with hairy or fluffy appendages that are carried or moved by wind (Booth and Schuman 1983; Stevens and others 1986). Proper depth of planting is generally governed by the size of the seed. However, the seed or fruit structure that is sown does affect planting depth. Care should be taken to distinguish between fruits and seeds. For example, dewinged utricles of fourwing saltbush are normally sown. The wings that are attached to the bracts are often quite large, as is the structure that encloses the small seed (utricle). Cleaning usually removes most of the wings. This dewinging reduces the size of the structure by three or four times. The degree or amount of wings, awns, or attached appendages removed in cleaning can affect the planting depth. In most cases, the entire structure must be incorporated in the soil to reduce or prevent differential drying.

Generally seeds of most species should be covered about 2.5 to 3 times the thickness of the cleaned seed. For small seeded grasses this would be more applicable to length than diameter. Ragsdale and others (1970) suggest not planting any deeper than seven times the diameter of the seed for plantings in Texas. The optimum planting depth for small seeded grasses, including Sandberg bluegrass and mutton bluegrass, is about 0.25 inches (0.64 cm). Planting depths of 0.5 inches (1.7 cm) are suitable for Idaho fescue, and 1 inch (2.5 cm) for larger seeds such as mountain brome and western wheatgrass (Hull 1966; Hull and others 1958; Reynolds and Martin 1968; Plummer and others 1968; Vallentine and others 1963).

Soil texture and the nature of the soil surface influence planting depth. There are few points of contact between the soil particles and the seedcoat with coarse-textured soils. Seeds have more points of contact with finer textured soils. The moisture is held tightly to the clay particles, but the soil capillaries are much finer (Young and others 1987).

Clay soils that expand and contract during wetting and drying may leave seeds in a pedestaled situation that is a harsher environment than is provided by a sandy seedbed (Koller and Hadas 1982). Clay soils generally hold more water than sandy soils, and rewetting is not required as often to maintain soil moisture for germination. Generally, seeds should be planted deeper in sandy soils than in clay or loamy soils.

Determining the appropriate seeding depth presents a paradox. The closer a seed is located to the surface, the less energy is required for emergence and initiation of photosynthesis. However, greater diurnal fluctuations in temperature and soil moisture occur near the surface that dry the soil and seed. The soil particles and soil atmosphere act as an insulation barrier to lessen changes in soil temperature and water availability (Chippendale 1949). Having at least some soil covering the seed prevents or lessens drying. The ideal seedbed is one in which the seed is firmly enclosed within soil particles to provide hydraulic conductivity of moisture to the seed (Collis-George and Sands 1959). Seed should be placed deep enough to prevent rapid drying but shallow enough to allow natural emergence.

Some seeds must be seeded on or near the surface because of physiological restrictions. Young and others (1987) list four principal physiological systems involved: (1) germination requires light or specific light quality; (2) seeds require fluctuating temperatures for germination; (3) nearly complete lack of seed reserves make rapid establishment necessary; and (4) other undefined physiological requirements that precondition germination to the surface seedbeds.

Seed placement in or on the soil influences germination through factors other than the availability of soil moisture. As mentioned, some seeds require light to germinate and burial in the soil restricts germination (Young and others 1987). In addition, soil temperature also regulates germination. Positioning seed at different depths in the soil allows seeds to germinate at different times due to differences in soil temperature. Young and others (1987) reported that soil temperature regimes have different effects upon the germination of ‘Fairway’ and ‘Nordan’ crested wheatgrass, ‘Covar’ and ‘Carbar’ canby bluegrass, and Russian wildrye.

In most situations seeding depth is based on the size or germination requirements of the primary species sown. Too often, seed mixtures are sown at one depth, based primarily on the requirements of grass species included in the mixture. If shrub and many forb seeds are sown with the grasses, different planting depths are required. Springfield (1970a) suggests that winterfat seed should be sown at a shallow depth, about 0.17 inch (0.42 cm). In his studies no emergence was achieved below 0.5 inch (1.27 cm). The optimum seeding depth for antelope bitterbrush is 0.5 inches (1.27 cm) (Basile and Holmgren 1957).

Planting seeds too deep has been a major reason for seeding failures. Forage kochia, sagebrush, rabbitbrush, Lewis flax, Palmer penstemon, and winterfat generally do best when seeded on top of disturbed soil (Stevens and Van Epps 1984). Most conventional drills place seed of these species too deep. Depth rings have been developed for use on the rangeland drill to control planting depth (Larson 1980). Depth rings, however, are fairly ineffective in loose soils and are not able to maintain shallow depths. Beside placing seed too deep in loose soil, drilling generally places the seed in the bottom of small furrows. Unstable furrows can fill in with soil following seeding before seedlings emerge. As a result seed drilled in loose seedbeds can be covered many times too deep.

With proper attention, seeds can be placed at a shallow depth when drill seeded. Also, seed can be placed at the bottom of stable furrows where moisture and temperature conditions are most favorable and seedlings ultimately appear (Hull 1970). In semiarid regions, planting in the bottom of deep but stable furrows is a useful technique as soil moisture is greater at this position in the seedbed (Tischler and Voigt 1983). Deep furrow drilling should be avoided on soils that are loose and unstable causing sloughing of the furrows.

Some soil compaction at the time of seeding can be helpful in regulating planting depths, especially in loose soils. Cultipacker seeders of various kinds have been developed (Larson 1980) to be used in seeding loose soils and planting at controlled depths.

Various drills and special furrow openers are now available and can be used to more closely control seeding depths (Baker 1976; Baker and others 1979; Haferkamp and others 1987; Hauck 1982; Monsen and Turnipseed 1990; Nyren and others 1981; Wiedemann 1987). Punch seeding and compact seeders are particularly useful in seeding loose soils and planting on the surface or at shallow depths.

It is essential that seeds having different depth requirements be sown separately at the appropriate positions in the soil. Where mixed seedings are planted, drill seeders should be used that can dispense seeds of different sizes in separate rows and at appropriate depths. Broadcast seeding followed by anchor chaining or harrowing plants seed at different depths in the soil, and is an appropriate technique for seeding mixtures. Two or more planting methods may be necessary to properly seed all species. Unless seeds can be correctly sown the chance of establishment is usually quite low. Overseeding or seeding heavily is not a corrective measure that can be used to substitute for improper seed placement.

A discussion of seeding machinery is presented in chapter 9.

Row Spacing

Row spacing recommendations have generally been developed for seeding irrigated and nonirrigated pastures, primarily with grasses. Most range-type drills use row spacings of 8 to 14 inches (20 to 36 cm). Maximum forage production of herbaceous species is not significantly affected by row spacing between 10 and 18 inches (25 to 46 cm) (Bement and others 1965; Conrad 1962; McGinnies 1960b; Springfield 1965). Consequently, most drill seeders have been designed to seed rows at these intervals. Wider row spacings on semiarid sites are generally recommended, particularly when native forbs and shrubs are seeded. Increasing the distance between rows is beneficial to the survival and growth of certain species. Plantings of globemallow, lupine, and Utah sweetvetch benefit from row spacings of between 15 and 18 inches (38 and 46 cm).

Narrow row spacings normally result in greater initial production (McGinnies 1960b; Sneva and Rittenhouse 1976), but differences disappear in later years. Narrow spacings usually foster better weed control (Cook and others 1967; McGinnies 1960b), particularly during the initial stages of community development.

Shrub seedings are becoming more important in range and wildlife projects. In general, row spacings for shrubs depend on the mature stature of each species sown. Normally, seedings of big sagebrush, winterfat, Martin ceanothus, fourwing saltbush, and antelope bitterbrush planted in rows are not adversely affected by high seedling density or close row spacings. However, seedlings of green ephedra, Saskatoon serviceberry, Stansbury cliffrose, curlleaf mountain mahogany, and skunkbush sumac are more easily stunted by severe intraspecies competition. The density of plants occurring within the seeded row has a greater affect on shrub establishment than does row spacing. In general, shrub rows should be at least as far apart as the maximum height of the shrub seeded.

Separate Row Seedings

Seeding individual species in separate rows is a useful technique (fig. 6 and 10) when using a number of species with different seedbed and establishment requirements. Seeding a mixture of grasses in certain drops of a drill, and individual forb or shrub species in other drops or furrows, allows all species a better chance to establish. Alternate row seeding has been a successful method of planting grasses with legumes or grasses with shrubs (Hafenrichter and others 1968; Leyshon and others 1981). Slow developing species benefit from being planted alone, particularly when seeded in arid situations. Grasses and legumes have been seeded in alternate rows as a means of increasing herbage production (Kenno and others 1987) and maintaining desired species composition (Gomm 1964; Kilcher 1982). Alfalfa has been most productive when seeded in separate rows from grasses on semiarid pinyon-juniper and big sagebrush ranges in Utah. Kilcher (1982) found that alfalfa comprised a greater percent of the plant composition when seeded in cross or alternate rows than in mixed rows with grasses—40 percent compared to 15 percent. Various native shrubs also exhibit better growth in separate row seedings than when seeded in mixtures with grasses.

The spacing of separate row seedings affects subsequent natural reproduction. Monsen and Shaw (1983c) found that antelope bitterbrush seedlings established better from mature shrubs originally spaced 10 ft (3.1 m) apart than from shrubs having a closer spacing. Closely spaced mature shrubs apparently shade or prevent new seedling establishment. Thus, row spacings may influence the ultimate composition of seeded species when shrubs and forbs are planted in alternate rows. Seeding shrubs in close row spacings will create shading and overstory competition. Understory species that are not able to tolerate shade can and will be eliminated. Row spacing of seeded shrubs is an important consideration in all communities.

Individual species can be seeded in alternate or separate rows with some broadcast-type seeders. The Brillon seeder has been successfully used in eastern Idaho to seed shrubs through one portion of the seedbox and herbs through a separate section (Richardson and others 1986).

Separate row seedings are important in reducing the amount of seed sown. By seeding individual species in separate rows, the seeding rate can be more carefully regulated. Drills or seeders that are used must be capable of metering seed at different rates for each seed drop. Partitions must be temporarily installed in the seedbox to keep seeds separated. With some equipment the seeding rates cannot be individually adjusted for each seed drop, and carriers must be added to dilute the material and regulate the flow and amount of seed sown.

No single factor—species selection, planting depth, or planting season—can be ignored when seedings are made. Each factor is important, and unless all conditions are favorable seedings will fail. Not properly covering the seed, or planting at the wrong season because of scheduling constraints, is unwise. Because seedings are too often scheduled to accommodate other activities, failures can result and considerable funds may be wasted. Problems associated with the expenditure of funds from one year to the next have plagued agencies for many years and have resulted in numerous seeding failures. Solving such problems would significantly improve the success of rehabilitation programs.