REVEGETATION

INTRODUCTION

One goal is to restore and improve habitat for native wildlife. An objective is to provide diverse vegetation and topography. Generally, diverse habitat supports more wildlife species. For example, a mosaic of shrubs, grasses, and forbs designed for sage grouse (Centrocercus urophasianus), mule deer (Odocoileus hemionus), and antelope (Antilocapra americana), will benefit other species including passerine birds, small mammals, and predatory mammals. The prey base will also benefit nesting raptors. Diverse topography (both macrosites and microsites) is important to encourage a variety of vegetation, cover, and reproduction sites (see section on landform and vertical diversity).

Several methods discussed in this section may be employed to increase vegetation diversity. Some of these techniques require more time than the normal bond period, or are not yet proven in the field. Selection of methods is a site-specific consideration.

Revegetation should be designed to control erosion, conserve water, improve water quality, improve forage for grazing or browsing animals, and enhance the aesthetic quality of the landscape (U.S. Soil Conservation Service 1988). Revegetation must also provide both structural and forage elements of wildlife habitat.

Vegetation which most accurately reflects the historic native plant communities and which is compatible with existing undisturbed adjacent vegetation should be restored (Camenzind 1983).

Certain native plants are difficult to reestablish for several reasons: competition with aggressive species; early seral condition of the ecosystem; low precipitation; failure to meet temperature and moisture requirements for germination every year; and a short bond liability period.

This section examines the revegetation process from recontouring the land to species selection and planting methods.

RECONTOURING PRACTICES

Landforms will permanently affect the composition of the plant community and should be developed first (Green and Salter 1987). Landform types include: rimrocks/cliffs; steep slopes/ridgetops; moderate to gentle slopes; and bottomlands. Some interim landforms are normal byproducts of mining operations and offer potential for development into beneficial features. For example, a remnant highwall might be stabilized and modified to create an "AOC" (Approximate Original Contour) feature such as cliff habitat. A final pit might also be used to create a pond or lake. Other landforms will be developed specifically for wildlife either during site operation or reclamation. For example, an overburden pile could be shaped and oriented to provide sheltered areas for wildlife.

Landform characteristics such as orientation, stability, shape, slope, and soil texture affect plant establishment and determine how water influences topographic development within a site (Green and Salter 1987). Landforms can also provide specific functions for wildlife such as escape terrain for big game; nesting sites for raptors; burrowing sites for small mammals; and protection from climatic extremes as well as visual or hiding cover from predators and human

disturbance. Topographic barriers can also be important as a shield for new vegetation from wind high wind velocities (U.S. Fish and Wildlife Service 1978).

Rough backfilling and regrading should provide varied landforms to establish ecological gradients needed to diversify plant communities over time (Schafer and Nielsen 1979). To some extent, this effort may be constrained by hydrologic and geotechnical integrity, ecosystem planning, and proposed land use (DePuit 1988). More distinct slopes, hills, valleys, and drainages are generally desirable. Regulations which require gentle, erosionally stable slopes and the prevailing interpretation of AOC, can make it difficult to restore sharp topographic gradients. However, a more progressive interpretation of the AOC regulation may allow development of highwall segments to simulate cliffs and rimrocks, provided these were part of the pre-mine topography. A varied topography enhances microsite formation. Vegetation diversity is a product of macrosite and microsite diversity.

Rolling terrain provides varied exposures, increases snow accumulation, and helps retain rainfall and runoff, thus reducing surface erosion (Green and Salter 1987). Rolling hills afford wildlife visual barriers from humans and predators, which is particularly important during the first 5 to 10 years after reclamation while plant cover is developing.

Two methods, free-dumping of overburden and recontouring, can be used to provide rolling terrain using above-grade features (Green and Salter 1987). Overburden can be dumped irregularly on flat areas or along existing slopes to create variously-shaped piles. It is important that follow-up grading work minimize the loss of surface irregularities on those areas. Existing site features such as spoil piles may be regraded to form gradually sloping ridges or rises that bisect the fall line of the hill at either right angles or very shallow angles. Use excavated material to diversify the shape of the pile. Depressions between ridges may be suitable for wetlands, small ponds, and mesic shrublands.

Below-grade features can be developed by excavating new depressions or swales or modifying existing site features (Green and Salter 1987). Suitable access routes need to be provided into steeper depressions. Below-grade features are often excellent locations for development of waterbodies. Slopes, contours, and elevations should be irregular, and the slopes into pits should be less than 44 percent. Below-grade haul roads can be recontoured to provide coulee-like approaches into pits.

Shallow swales can be excavated on flat areas or gentle slopes (Green and Salter 1987). These landforms are particularly useful in dry areas where collection of rainfall and snowmelt enhances growth of trees and shrubs. Depressions should be 5-15 m wide, 10-20 m long, and at least 1-2 m deep, with gently sloped (<3:1) approaches.

Where possible, locate spoil piles to screen wildlife from heavy industrial activity, or contour them irregularly to provide a variety of landforms and aspects (Green and Salter 1987). For economic reasons, these features must be planned and started early in the operation. Berms intended for screening should be at least 2-3 m high. A variety of slope angles, aspects, and irregular contours built into large piles should provide some shelter from prevailing winds, and varied exposure.

North-facing slopes present the most favorable growing conditions; next east-facing, third, west-facing; and last, south-facing (Cook 1988). South-facing slopes may be very difficult to revegetate, even on rather gentle slopes (3:1), in areas of limited precipitation (25-31 cm). Revegetation is easier on north-facing slopes of similar gradients.

A 3:1 slope on south and west aspects in arid climates should be the minimum for long-term revegetation establishment (Cook 1988); whereas north and east slopes can have a somewhat steeper slope. When in doubt, try to approximate a 3:1 or lower gradient to reduce risk of failure.

TOPSOIL REPLACEMENT AND STABILIZATION

Soil Stabilization

Soil must be stabilized before other phases of reclamation can proceed (Hodder 1975). High relief areas designed to enhance wildlife habitat are the most difficult to stabilize. Initial treatments depend on climate, macrotopography, and edaphic factors (DePuit 1988). Objectives include short-term erosion control and water conservation; and long-term stabilization through successful vegetation establishment (Hodder 1975; Verma and Thames 1978).

Topsoil Depth

Because mines are required to distribute topsoil uniformly, the practice of varying topsoil depths to increase heterogeneity and vegetation diversity has remained largely untested in reclamation. The loss of varied topsoil, slopes, aspects, and chemical and physical properties reduces the inherent heterogeneity of the reclaimed ecosystem (Munshower 1994). Uniform topsoil depth may impede development of a diverse plant community on the rehabilitated landscapes.

In arid or semiarid areas, topsoil tends to be thinner on the natural slopes near hilltops and thicker near bottoms (Munshower 1994).

Allerdings and Redente (1983) documented higher plant diversity, but lower production on shallow soils, suggesting there may be a trade-off at times between the two. Redente et al. (1982) determined shrubs benefitted from greater topsoil depths; grass biomass increased to a point; and forb biomass was negatively affected. Optimal topsoil depth for grasses is 30 to 100 cm (DePuit 1980). The optimal depth for shrubs and forbs has not been as well studied (DePuit 1980).

Direct Application vs Stockpiling

Most Wyoming coal mines respread stripped topsoil directly onto regraded surfaces whenever feasible. This practice is termed "direct haulback." Viable seed in the topsoil is one of the more successful ways shrubs become established on reclamation. Advantages of reapplying freshly stripped topsoil include retention of fertility and other physico-chemical characteristics; retention of symbiotic mycorrhizal associations; accelerated microbiological activity; reestablishment of indigenous plants from seeds and live tissues; accelerated soil genesis and plant succession (DePuit 1988); and reduced materials handling costs (Green and Salter 1987). The best time to transfer topsoil is during the late fall to early spring to ensure optimum plant survival (Green and Salter 1987).

Shrub germination could be augmented by mulching live shrubs into the topsoil or using the removed shrubs as ground cover and potential seed source on the replaced topsoil (Overthrust

Industrial Association 1984). The shrubs would inhibit soil erosion, intercept precipitation, reduce splash erosion, and retard runoff velocities. S. Tessmann (Wyoming Game and Fish Department, pers. comm.) suggested using a Rotoclear to improve germination in direct-hauled topsoil. The Rotoclear chops and mixes plants with the upper six to eight inches of topsoil. An extra step is involved in topsoil stripping and reapplication, so this technique may have greatest utility where shrub patches are specifically planned.

Segregating topsoils associated with specific vegetation types (e.g., salt desert shrubs, sagebrush, or other vegetation type), then reapplying them in a mosaic could increase plant community diversity (McArthur 1981). This technique should be further investigated.

Microorganisms

Microorganisms accelerate revegetation by enhancing biological activity and nutrient cycling, and by buffering plants from environmental stresses (Jackson 1991). Microorganisms also aid in soil structure formation (Rothwell 1984; Rothwell and Eagleston 1985; Fresquez and Aldon 1986; Fresquez et al. 1987a,b, 1988; Harris and Birch 1989; Harris et al. 1988).

Microbial associations are extremely important for initial revegetation success. Soil handling practices, soil amendments, and revegetation practices which affect microorganism reestablishment, are being improved through ongoing research (Cundell 1977; Klein et al. 1984).

Soil microorganisms include: bacteria, fungi, actinomycetes, algae, protozoa, and viruses. For land rehabilitation, the two most important groups are bacteria and fungi (Jackson 1991).

Bacteria

Bacteria mediate many of the nutrient cycles in self-sustaining ecosystems and often influence plant uptake by altering the physico-chemical environment around their roots (Jackson 1991).

Restoration practices such as mulching and direct haulback greatly enhance reestablishment of microbial and enzyme components (Jackson 1991). Bacterial inoculums, such as seed coatings or root dips have also been developed for plant species used in revegetation (Rothwell and Eagleston 1985). Hodder (1976) provided adequate inoculant for legume establishment and nodulation by collecting topsoil under undisturbed native stands of the desired legume and then spreading it on plots to be seeded.

Mycorrhizal Fungi

Williams et al. (1974), Aldon (1975), Reeves et al. (1979), Trappe (1981), and Williams and Allen (1984) have investigated the importance of mycorrhizal fungi for plant reclamation. Mycorrhizae-infected plants grow better than uninfected plants, especially on low fertility soils (Black 1968; Buckman and Brady 1969). The symbiotic association with roots is essential for several native shrub species. Types of mycorrhizae include ectomycorrhizae, vesicular-arbuscular mycorrhizae, and ericoid mycorrhizae. Techniques are currently being developed to accelerate colonization by mycorrhizal fungi and other microorganisms are currently being developed (DePuit 1988). Direct haulback of topsoil is generally sufficient in reestablishing mycorrhizae on reclaimed lands. However, if the topsoil has lost its mycorrhizae, or if an otherwise suitable

subsoil is used as topsoil, the mycorrhizae should be added to the soil or seed mixtures (Brown et al. 1986). Noncommercial mycorrhizae can be gathered from puffballs or other fruiting bodies, ground up, and mixed with seeds or sprayed on the site in a water solution. Commercial mycorrhizae is not available for most species other than nursery grown trees.

Plants associated with endomycorrhizae include fourwing saltbush (Atriplex canescens), winterfat (Ceratoides lanata), true mountain mahogany (Cercocarpus montanus), bitterbrush (Purshia tridentata), and big sagebrush (Artemisia tridentata) (Aldon 1975, 1976; Williams and Aldon 1976).

Root dips made from fungus cultures have been manufactured for several plant species, such as pines (Pinus spp.) (Cordell et al. 1987a, b) and have been used to improve tree seedling survival on acidic restored land (Jackson 1991).

Vesicular-arbuscular mycorrhizae (VAM) fungal inoculum is carried by animals and deposited in feces and carcasses (Jackson 1991). VAM infections enhance survival and growth of plants in spoil materials since numbers of VAM decrease when land is disturbed.

SEEDBED PREPARATION

Basic Methods

The seedbed should be firm to conserve moisture at the surface, with a roughened texture to cover the seed, reduce erosion, and improve water infiltration (Koehler 1985). A firm seedbed increases rates of seedling emergence, growth, survival, moisture retention, lateral root distribution, and root hair development near the surface (Hyder et al. 1955; Hyder and Sneva 1956). However, the seedbed should not be compacted after drilling seed because this restricts emergence, soil aeration, and the number of primary roots (Hyder et al. 1955; Hyder and Sneva 1956).

The following methods are suitable for seedbed preparation (U.S. Soil Conservation Service 1988):

1) Conventional method: A firm weed-free seedbed is prepared.
2) Cover crop:
   a) Prepare a suitable seedbed for the cover crop.
   b) Select an adapted crop and seed according to the following specifications:

Crop	Seeding Rate Dryland Lbs/Ac	Depth of Planting	Seeding Method	Seeding Dates
Spring grains	40-60	5 cm	Drill	April 1-July 1
Sorghums	10-15	5 cm	Drill	May 15-July 15
Sudangrass	10-15	4 cm	Drill	May 15-July 15
Foxtail millet	12-18	2.5 cm	Drill	May 15-July 15

   c) Limit small grains to regions receiving at least 25 cm annual precipitation.
   d) Mow or harvest crops as necessary to prevent seed production.
   e) If erosion control is necessary and a cover crop cannot be established, mulching is recommended (see the section below on mulching).
3) Stubble mulch fallow (see section on mulching).

4) Existing stubble: Native species can be interseeded directly into weed-free stubble. Volunteer grain is generally not a problem in Wyoming. In fact, volunteer grain can provide a food source for wildlife the first two or three growing seasons.

Valentine (1989) describes the ideal seedbed as:

1) very firm below the seeding depth
2) well pulverized and mellow on top
3) not cloddy nor puddled
4) free from live, resident plant competition
5) free of seed of competitive species
6) moderate amounts of mulch or plant residue on soil surface.

Mulch

Plant establishment can take longer in dry regions. Mulching may help shorten the process (Kay 1978). Mined land regulations require a mulch for arid land reclamation (Cook 1988). Mulches range from straw, to shredded paper, to films of petroleum products sprayed on the soil surface, to sheets of plastic, to stubble left on a field after haying (Lyle 1987). Straw, hay, and cellulose mulches are most commonly used in reclamation; straw and hay are used when seeds are sown dry, and cellulose fiber is used when seeds are sown in a water slurry.

Mulching improves moisture infiltration, helps disperse the mechanical impact of rain, offers some protection from overland flow, prevents crusting, improves soil structure formation, improves nutrient supply, reduces moisture loss, and lowers midafternoon temperatures in the top 2.5 cm of soil (Springfield 1972; Kay 1978; Lyle 1987; DePuit 1988). Some mulches promote plant growth and soil development by improving soil structure, water-holding capacity, and nutrient availability. Potential problems include the introduction of seeds of noxious species with some hay and straw mulches, and in Wyoming the wind can blow loose mulch from the surface, unless it is crimped. However, properly anchored, mulches will reduce surface wind velocity (Kay 1978). A heavy duty crimper is the best way to keep the mulch in place, but even heavy crimpers are not effective on hard compacted soil. Unless clean straw or hay is used, grain and weeds may germinate and compete with native range plants (Gould et al. 1975).

Mixing some of the pre-mine vegetation with hay or straw will aid in reestablishing desired plant species.

Usually straw and hay mulches are applied at one to two tons/acre (Lyle 1987). A uniform application of mulch is very important; thick applications can retard or prevent seed germination or establishment, and thin applications may not provide the benefits of mulching.

Except on critical slopes, standing stubble mulch is generally a less expensive, but effective alternative to conventional mulching if properly established under favorable conditions (DePuit et al. 1978; Schuman et al. 1982; Cook 1988). Standing stubble is a term for a cover crop grown to stabilize topsoiled spoils before the final plant species are seeded (Brown et al. 1986). Stubble mulch is usually planted in the spring before seeding in the fall or seeding the following spring (Brown et al. 1986; Cook 1988). These crops are sometimes mowed before maturity at about 25 to 30 cm in height (Cook 1988) or else a sterile variety is used (Brown et al. 1986) so that seed are not produced to compete with the reclamation species. The mowed portions falls to the ground to remain as litter. To reduce competition, the stubble crop should not be used as a cover

crop when the seed mixture is seeded at the same time. Using domestic winter wheat or domestic rye in stubble much is also not recommended as these species are severe competitors with seeded native range species. They lead to failure in most Western arid climates because volunteer stands are produced year after year.

Standing stubble can be more effective than crimped straw at catching snow and preventing wind erosion (Brown et al. 1986). Other advantages of standing stubble include: it lasts longer because even crimped straw can be blown away; soil temperature fluctuations are lessened; there is higher total water infiltration; the cost is less than for crimping straw; and the chance of weeds infesting the site is lower.

Wood fiber is frequently applied with a hydroseeder when it is used as a mulch on steep slopes (Cook 1988). The seed mix is included in the hydroseeder to reduce the cost of application; however, this reduces the viability of the seed in the mixture and leaves most of the seed above the soil surface in the wood fiber mulch. Many seeds germinate, but the mulch dries, the seeds do not have a chance to project roots into the soil, and they consequently die.

Hydromulching (spraying a slurry of water and mulch) is generally used only for problem areas or on slopes too steep to mulch with conventional equipment (Brown et al. 1986).

Microtopographic Manipulations

After the seedbed has been firmed, the soil surface can be roughened by various methods to retard runoff and increase moisture infiltration (DePuit 1988). Due to excessive runoff, a large portion of precipitation is ineffective for plant establishment (Dollhopf 1985). Microtopographic manipulations also reduce surface velocity of wind and flowing water, lessening erosion and sedimentation. Treatments should be tailored to climatic, edaphic, and topographic conditions, and revegetation practices. Primary tillage and microimprinting are satisfactory for level to gradually sloping sites. Moderate slopes may require contour trenching, deep basins, or contour terracing. In arid climates, progressively more extreme manipulations may be needed.

Furrows

Grooves and furrows can improve germination and seedling establishment (Branson et al. 1966; Soiseth et al. 1974; Valentine 1989). However, windblown silt and sloughing may bury seeds too deeply in deeper furrows. On level surfaces, wind erosion can expose and dislodge seeds from drilled stands (McGinnies 1972; Koehler 1985). Planting shallow furrows or alternating deep and level furrows may provide the best germination (McGinnies 1972).

In saline areas, furrows can reduce salinity at the soil - seed interface because higher evaporation on the ridge draws salt upward by capillary action. This concentrates it in the ridges away from the seeds in the furrow (Koehler 1975). Furrow bottoms conserve moisture because air movements, soil temperatures, and direct sunlight are reduced (Hull 1948; Koehler 1985). Furrows also trap drifting snow which increases growing season soil moisture. Contour furrows in southeastern Montana held an average 22 mm more moisture from snow than non-furrowed areas (Neff 1980).

Gouges and Basins

Pitting is the creation of small basins or surface pits with an offset disk or modified plow. It has been an effective soil treatment in Wyoming (Branson et al. 1966; Rauzi 1968). Rauzi (1968) reported infiltration rates were higher ten years after pitting in all pitted treatments. In southern Arizona, Slayback and Cable (1970) found larger gouges, 15 cm deep, 45-60 cm long, and 1.5-2.4 cm wide, increased plant growth 2.5 times over conventional pitting and 5 times over untreated range. Larger pits increased the effectiveness in reducing runoff and prolonging soil moisture availability.

Gouging is recommended as a short term erosion control treatment, lasting 1 to 2 years (Dollhopf et al. 1985). It should be used on slopes less than 20 percent. Gouging can substantially reduce erosion during the first year of plant establishment.

Larger basins, constructed with a bulldozer, have been successful on mine spoils in Montana (Sindelar et al. 1973). Both the gouger and dozer basin blade have gone through development and can now be efficiently used on surface-mined lands (Dollhopf et al. 1985). Dollhopf et al. (1985) recommend dozer basins for all mined land slopes, especially those with gradients greater than 20 percent, where effective erosion control is needed for a long time. Dozer basins are semi-permanent, lasting from about 10 to more than 50 years. They eventually recede back into a smooth surface similar to the premine landscape.

Compared to a control, surface water runoff on dozer basin treated watersheds was reduced by 75% during a three year period (Dollhopf et al. 1985). Gouges and basins concentrate water into depression bottoms creating wet zones for plant establishment.

Experienced operators can gouge 1.0 to 1.2 ha per hour, or approximately 6200 depressions per ha (Dollhopf et al. 1985). The gouges are about 90 cm long, 38 cm wide, and 12 cm deep. Dozer basins can be dug at the rate of 0.8 to 1.0 ha per hour, or about 620 depressions per ha. Dozer basins average 5 m long, 2 m wide, and 1 m deep.

The seedbed should be immediately broadcast seeded after the manipulation since wind and water erosion may cause deterioration in the quality of the seedbed (Dollhopf et al. 1985).

Treated surfaces should be fenced, as trampling can quickly diminish effectiveness of gouging and shorten the life of dozer basin treatments (Dollhopf et al. 1985).

Ripping

The purpose of ripping is to break or shatter compacted subsoil layers that may restrict root growth and moisture penetration (U.S. Fish and Wildlife Service 1978).

DEVELOPMENT OF SEED MIXES

Selection Criteria

Green and Salter (1987) believe the two most important considerations in designing revegetation for wildlife include: plant communities which are compatible with the physical elements of the sites and a combination of plant communities and physical elements fulfill the needs of key wildlife species. To select appropriate plant species, information on wildlife use of plants on and around the site prior to development is most useful.

DePuit (1988) recommends several considerations for selecting revegetation materials.

1) Site adaptation characteristics - edaphic tolerance; climatic tolerance; growth form; productivity; reproductive characteristics; longevity; and phenology. (Collecting seed from local sources helps in meeting these characteristics.)
2) Ease of establishment.
3) Compatibility with other plant species - allelopathy, mutualism, and competitive relationships.
4) Utility for post-mining land uses.
5) Commercial availability and cost.

It is critically important to design compatible mixes with balances of plant species which optimize colonization and succession (DePuit 1988). Interspecific (synecological) relationships are among the least understood aspects of rangeland vegetation. There may be several reasons why certain plants fail to grow in seed mixtures. Mine operators could improve our knowledge by noting which plants are compatible and which are not, including reasons (even if speculative).

For example, crested wheatgrass (Agropyron desertorum) is no longer permitted in reclamation seed mixes because of its aggressive competitive nature and longevity. Schuman et al. (1982) followed development of a tilled rangeland site seeded with crested wheatgrass and four other perennial grasses. By the fourth growing season, 95% of the biomass was crested wheatgrass, though it comprised only 25% of the seed mixture.

Smooth brome (Bromus inermis) is another exotic so aggressive it may rapidly dominate a new minesoil plant community even if it comprises a low percentage of the seed mix (Munshower 1994).

DePuit (1982) suggested procedures to enhance interspecific compatibility, although they have not been fully tested.

1) Include species of varying seasonal grown patterns (phenologies).
2) Include species with different growth forms (above and below ground).
3) Calculate appropriate seed rates for individual species based upon differences in characteristics (vigor, competitiveness, etc.) and ultimate composition objectives.

Thornburg and Fuchs (1978) noted that selecting the proper ecotypes or cultivars for the specific site is as important as selecting the proper species. Choose seeds that are proven adapted to climatic, edaphic, and topographic features at the reclamation site. Collection of native seed from local sources may be necessary to improve establishment of some species. For example, Indian ricegrass (Oryzopsis hymenoides) should always be collected near the site where it is to be planted. When native plant seed is collected, information is required on time of seed ripeness, proper method of handling, storing, and treating seed before planting (Yoakum et al. 1980).

Palatability, persistence, aggressiveness, and cost are additional considerations (Koehler 1975). Species that remain green later into the summer should be included to extend availability of succulent forage (Cornelius and Williams 1961). Species of similar palatability should be planted together, otherwise more palatable ones will decline with heavy grazing (Hull and Homgren 1964). Less palatable plants should be selected to discourage wildlife use in areas sensitive to overutilization, erosion, or hazardous areas such as roadsides.

Although exotic species may establish more rapidly than native species, once established, native species require little or no maintenance (Green and Salter 1987). Exotic species may also displace desirable native species, or ultimately fail because they are poorly adapted for long-term persistence. Exotic species are discouraged in Wyoming. Generally, locally adapted, native plant

stock should be used in preference to agronomic species (Aldon 1976; Eddleman 1979; McKell 1978).

Native species studied by Redente and Grossnickle (1982) developed more extensive root systems than introduced species, and penetrated sub-surface barriers such as retorted oil shale or rocks; introduced species did not. They recommend using native species for revegetation on shallow soils or where limited topsoil is available for reapplication. Native species should be emphasized along edges, fencerows, and drainages (Camenzind 1983).

Mixes designed for sites receiving less than 41 cm annual precipitation should contain at least 50% native species (U.S. Soil Conservation Service 1988). In practice, 100% native species is preferred. Introduced species may be considered where they contribute to the land use and do not outcompete desirable native species. Seed viability of interstate shipments should be tested one year prior to seeding. Intrastate seed should be tested nine months prior. Soil Conservation Service (SCS) technical range site descriptions list species adapted to each range site. Individual seed rates can be adjusted to meet particular conservation objectives. All rates assume monotypic plantings of the individual species. For mixtures, multiply respective rates by the inverse of the number of species included. Use half the minimum Pure Live Seed (PLS) rate for row spacings wider than 60 cm, interseeding, and other renovated rangeland.

Seeding rates must be based on PLS in order to evaluate seeding rates from species to species and from seed lot to seed lot (Brown et al. 1986). Much of the literature recommends rates for seeding individual species; there are few available data on seeding rates for revegetating mined lands with seeding mixtures (Depuit et al. 1980). When several seeding mixtures are used, each mixture with species adapted to different specific sites, less total seed is required (Brown et al. 1986). Relative amounts of each species will vary depending on the site each mixture is designed to seed. For example, western wheatgrass (Agropyron smithii) will often dominate the seed mixture on lowlands in the Northern Great Plains, whereas on ridges, it will be minor component in the mix.

Because cool-season species often outcompete warm-season species, warm season species seeding rates are increased in proportion to the amount of warm season plants desired (Brown et al. 1986). Competition must be accounted for by adjusting the proportions of each species in the seed mix, and some species should probably not be seeded together in a mix (e.g., some shrubs and cool-season grasses).

Ideally, to achieve greater diversity, topsoil would be replaced at shallow depths on a hilltop and would vary to 60 cm or more in an ephemeral stream bottom (Munshower 1994). Several different species mixes would be applied on different slope positions, aspects, and exposures instead of one multiple purpose mix (Munshower 1994). However, in practice a homogeneous topsoil is generally reapplied at the same depth and often only one mix is seeded along a slope (Munshower 1994).

Most degraded soils are planted with one or a limited number of seed mixes because of the expense of seeding different combinations of plant species (Munshower 1994). The single seeding generally contains a broad mixture of species, with the assumption that different combinations of seeds will successfully establish in different micro- and macrohabitats. However, disturbed lands contain fewer micro- or macrohabitat-influencing factors than existed premining. Climate and topsoil are the overriding influences on seeded plant germination, establishment, and growth. Species that germinate and establish will be relatively uniform throughout the seeded area in a particular growing season, even though a broad seed mix was used. The same seed mix

on a different site or in another growing season can result in an entirely different vegetation response since climatic patterns and surface soil coverings change from year to year.

Succession

Plant succession is rarely mentioned in revegetation reports. Natural adjustments will occur after revegetation efforts. Not all plants will germinate or survive; weedy species may invade; grazing pressure from a wide range of wildlife may cause otherwise successful plants to die; and a wide range of influences may keep a disturbed but rehabilitated site in a seral stage of low productivity (Reynolds and Paulson 1970).

Early successional plants will often colonize reclaimed surfaces. After three or four years, plants in the original seed mix gradually displace pioneering species as biotic and abiotic conditions change (Allen 1983; Hatton 1986). Generally, early infestation by annual weeds does not significantly affect later succession by the seeded species.

Complete stabilization of a reclaimed ecosystem may take a very long time (much longer than the bonding period) and has yet to be demonstrated on drastically disturbed land. A major objective should be to establish well-adapted species which reduce large annual fluctuations in plant density and to have the annual productivity of plant biomass be commensurate with the potential productivity of the site (U.S. Fish and Wildlife Service 1978).

DePuit (1988) contends any plant species selected for revegetation must contribute to at least one of two purposes. Certain species may be selected to fulfill successional roles or occupy niches created by reclamation. Selection may also be based upon utility for specific rangeland uses.

Early seral species accelerate succession by (DePuit 1988):

1) Stabilizing soil
2) Increasing organic build-up
3) Enriching soil nutrients (e.g., nitrogen fixing by legumes)
4) Retarding less desirable pioneer species through competitive exclusion.

PLANTING METHODS

Planting methods depend on the species to be seeded (e.g., shrub seed should be broadcast), topography, accessibility, rockiness or other debris cover, soil, and available equipment. In arid and semi-arid regions, greater attention must be given to precise timing, seed placement, and capabilities or limitations of the site (Koehler 1975).

Climatic Considerations

The Northern Great Plains are generally characterized by annual mean rainfall of less than 40 cm (Munshower 1994), with periods of drought relatively common. About one half the annual precipitation normally occurs as rain or snow during late April, May, and June. Limited or no precipitation occur during July and August. In September and October, the probability of precipitation increases, and a fall vegetation greenup happens in most years. When spring rains fail or are of limited amounts, drought and seeding failure are probable.

Heat and cold extremes also occur in our region. Extremes are not enough to prohibit plant growth, but a range of more than 80 degrees C is wide enough to limit the number of species that can successfully complete their life cycles in this area (Munshower 1994).

Vegetation establishment is more difficult in areas receiving less than 23 to 25 cm of annual precipitation (Stoddart 1946; Plummer et al. 1968; Cook et al. 1974). Plummer et al. (1968) determined successful establishment requires at least 5 or 8 cm of precipitation during the active growing season. Problems include: extreme variability in rainfall patterns; low humidity; high diurnal temperatures, extreme temperature fluctuations, and high evaporation (Koehler 1985). It is important to select drought tolerant species under such extreme climatic conditions.

Areas receiving 31 to 38 cm are easier to revegetate (Cook et al. 1974), especially when infiltration is enhanced, and runoff, evaporation, and leaching are reduced (Power et al. 1978; Koehler 1985).

Plant species vary in temperature and moisture requirements for germination, specific conditions may favor certain species in a mix. Conditions may be favorable briefly, sometimes only 3 to 7 days each year (Jordan 1983). Varying conditions coupled with diverse germination requirements account for some of the annual differences in species composition, total production, and in production of individual species (Leonard et al. 1988). Tueller and Monroe (1975) found production varied as much as 1200% between years for some Great Basin range ecosystems. The kind, gross abundance, and proportion of species within a community are directly linked to different water consumption rates among species (Leonard et al. 1988).

Many of our native species are drought resistant, including shadscale (Atriplex confertifolia) and winterfat, which have the ability to extract water from soils having moisture potentials below -75 bars (Moore et al. 1972).

Many plant species are also faced with extremes in temperature. Low temperatures can present problems for seedling survival. Snow serves as an insulation against low ambient temperatures. During winters with little or no snow cover, or where areas are blown free of snow, seedlings can be exposed to lethal low temperatures (U.S. Fish and Wildlife Service 1978). In general, native species are better adapted to local climatic extremes than introduced species (Plummer et al. 1968).

Season and Sequence of Seeding

Appropriate planting dates depend on seasonal weather patterns, plant species, germination, and growth characteristics. Planting should immediately precede the most favorable period for establishment, when moisture is most dependable and abundant for at least a two-month period (Stoddart 1946; Koehler 1985).

In general, sowing seeds in late fall or winter helps overcome the dormancy problem for many native species having seed dormancy. McGinnies (1960) recommended planting seeds during late fall or winter and allowing them to germinate under conditions as natural as possible, since various species have different requirements for moisture and temperature.

Intermountain Region

45-65% of precipitation in the Intermountain Region comes in winter in the form of snow. The summers are typically dry and the winters are moist to wet. In valleys and foothills, late fall

seeding is recommended (Valentine 1989). Planting seeds of grasses, shrubs, and forbs late enough so that germination is prevented by cold weather until the following spring results in minimal winter kill. Early spring seedings do well on higher, less arid sites, depending on spring precipitation (which cannot be predicted at seeding time). Late May and June seeds are generally the least successful, and these seedings fail to catch up in later years.

Northern Great Plains

Throughout the Northern Great Plains and Intermountain Region, fall planting have usually been recommended (Plummer et al. 1968; Cook et al. 1970; Houston 1971; Lang et al. 1975).

Cool-season grasses or grass-legume mixes planted in late summer will establish in the fall if moisture conditions are favorable (Valentine 1989). If late summer moisture conditions are unfavorable, cool-season grasses should be seeded in late fall or winter prior to soil freezing, or in early spring. The U.S. Soil Conservation Service (1988) recommends seeding mixes which are predominantly cool-season species after the soil temperature has dropped sufficiently to prevent fall germination. Seeding may extend through April 15 provided weather and soil conditions permit adequate seedbed preparation. Late spring and early summer seedings of cool-season grasses should be avoided. Grass-legume mixes should be seeded in early spring (Valentine 1989). Seedbeds need to be well stabilized against wind erosion for seedings in late fall to early spring, otherwise seeds and seedlings may be blown away. Sowing in spring reduces the time that rodents have to find the seed before it germinates (Yoakum et al. 1980).

Predominantly warm-season species should be seeded in early spring through May 15 (U.S. Soil Conservation Service 1988), although Valentine (1989) recommended planting warm-season grasses in mid to late spring, depending on the species and latitude. Late fall and early spring frost can damage seedlings of warm-season grasses, which is why spring seeding is favored over fall seeding (Valentine 1989). Summer seeding of warm-season grasses is not recommended as it is seldom successful.

Warm-season grasses may be difficult to establish because the climate favors the initial establishment of cool-season grasses (DePuit 1988). Planting cool-season grasses after the warm-season grasses have become established may help overcome this problem, but it also sets the bond period back.

Note: Native shrubs should <u>not</u> be combined with cool-season grasses in a mix, because competition will preclude establishment of the shrubs.

Single-Stage Seeding Strategies

The major reason for using mixtures is to put different species in the site conditions where they are best suited when using a single seeding strategy.

Grasses drilled in alternate rows with shrubs allows better establishment of slower establishing shrubs than when both are seeded together. If shrubs are planted with grasses, the amount of shrub seed should be increased and the amount of grass seed decreased to reduce competition.

Multiple-Stage Seeding Strategies

Multiple-stage seeding is more costly and time consuming so its use may be limited. At times, weed infestation can become a problem after the first stage is seeded. DePuit (1988) recommends multiple stage seeding when single-date seeding yields unacceptable results. Where this approach provides consistently reliable results, it may be prudent to use it more routinely.

DePuit (1988) describes three multiple seeding strategies:

1) Pioneer cropping (i.e. stubble mulching) -- this is the most feasible, and has been used successfully.
2) Multiple dates for initial seeding of perennial species (same growing season).
3) Deferred interseeding (successive growing seasons).

DePuit (1988) suggested seeding subgroups of species according to seasonal germination requirements, to achieve optimum growth. A cool season species might be seeded in the early spring, warm season species in the late spring, and species that require overwintering to break dormancy in the late fall.

However, cool season species are highly competitive, and if established first, may preclude germination of warm season grasses and shrubs. To alleviate this problem, a multiple stage seeding strategy that would allow slower-establishing species to be seeded without competition the first growing season, followed by minimum tillage interseeding of more vigorous species (e.g., cool season species) prior to the second or third season. In specific situations, this practice has been successful (Coenenberg 1982); however, there is a high chance of weed infestation.

Another method of multiple stage seeding involves long-term deferral of interseeding. Certain desirable species may require a period of site conditioning by antecedent vegetation (DePuit 1988). After suitable conditions develop through the effects of initial vegetation, desired species may be interseeded. This strategy is probably not viable in Wyoming because it may substantially increase the bond liability period.

Seeding Techniques

Seeding method should be selected based upon characteristics of seed mix species such as depth requirements and physical seed characteristics. Site-specific factors such as topography and soils can influence the nature of seedbed preparation and the effectiveness and practicality of various seeding methods (DePuit 1988). Sometimes a combined approach is most effective.

Direct seeding is a method which applies seed mixes directly onto (broadcast seeding) or into (drill seeding) bare regraded soil, after varying degrees of surface preparation. It is the most common, successful, and cost-effective method of revegetation (DePuit 1988). Ground seeding, aerial seeding, and hydroseeding are types of broadcast seeding.

DePuit (1988) concluded seeding works well for sexually reproducing grasses and forbs in climates which promote rapid germination and early growth. Seeding has not proved as effective under more severe climatic conditions, or for woody species and vegetatively reproducing species.

Seeding success depends on adequate seedbed preparation, timing, methods, and rates of seeding. Various treatments have been investigated in the literature. The following references provide more detailed discussions of seeding methods: Plummer et al. (1968); Cook et al. (1974); Packer and Aldon (1978); DePuit (1982); and Ries and DePuit (1984).

Drill Seeding

Seed is placed in a soil furrow and covered with a certain amount of soil. Advantages to drill seeding include (Brown et al. 1986): a minimum amount of seed is needed; good seed distribution; seeding depth is controlled; and good seed coverage. Disadvantages include (Brown et al. 1986): more limitations than for broadcast seeding techniques; steep slopes cannot be drill seeded; drills may not handle small seeds or seeds with awns, plumes, or wings; seeds of varying sizes and shapes may be unevenly distributed; and drills may need a carrier such as grit, sawdust, or rice hulls to keep small or trashy seed flowing.

A grass drill should be used rather than a grain drill. Grass drills should possess a separate box for small seed, a seed agitator, and a force-feed mechanism that allows awned seed and fuzzy seed to be drilled along with smooth seed (Cook 1988). A disk-type drill is preferred to a shovel-type planter mechanism in most soils as the latter plants the seed too deeply in most seedbeds.

Seeds should be placed in the bottom of the furrow; seeds placed in the sides or ridges of furrows are less likely to survive (Brown et al. 1986).

Grass and forb seed can either be broadcast or drilled. If drilling grass and forb seed, the depth should be 0.6 to 1.3 cm in loam or heavier textured soils, and 1.3 to 1.9 cm in light textured soils, but never less than 0.6 nor more than 2.5 cm (U.S Soil Conservation Service 1988).

Broadcast Seeding

Successful broadcast seeding depends upon proper seedbed preparation, seeding rates, and seed covering (Brown et al. 1986). Broadcast seeding is preferred on steeper, rougher sites; requires less tillage (thus reduces initial erosion); is more effective for disseminating unclean or fluffy seed; reduces initial competition; and is better suited for diverse mixtures of species with varying seed characteristics and depth requirements. On the other hand, drill seeding usually assures adequate soil coverage of the seed; flexibility in mulching and interseeding; and more precise rates of seed dispersal.

Generally, broadcast seeding is an inexpensive, rapid method of seeding. Ground seeding is the most commonly used broadcast seeding. Aerial seeding is rarely used on mined lands because results have been disappointing, probably due to the seed not being covered (Brown et al. 1986). Hydroseeding is relatively expensive and requires large amounts of water. It is usually used for steep slopes, rough terrain, or other access-problem areas. After hydroseeding, the seed is usually covered by another spray of mulch.

Many authors recommend using up to twice the recommended PLS amounts for broadcast seeding than for drill seeding (Plummer et al. 1968; Packer and Aldon 1978; Packer 1979; DePuit 1980; Vallentine 1989). This can make broadcast seeding more expensive when compared to drill seeding.

Disadvantages to broadcasting seed include (Brown et al. 1986): patchy seed distribution, especially if seeds are of different size and weight; susceptibility to depredation by birds, insects, and rodents, even when covered with soil by pressing or dragging afterward; and less seed coverage than drill seeding.

Note: Native shrub seed should not be drilled; native shrub seed should be broadcast seeded and usually at double the specified rates. Native shrubs will generally not germinate if drilled.

Transplants

Transplanting is expensive and usually limited to small areas where seeding has failed; where mature plants are needed to provide a seed source; or where "shrub islands" are planned to enhance spatial and vegetation/habitat diversity (Ambrose et al. 1983; Overthrust Industrial Association 1984; DePuit 1988).

Transplants obtained from local sources are ecologically adapted materials which can also inoculate soil microorganisms and provide immediate site stabilization (DePuit 1988).

Some advantages of transplants include immediate wildlife cover, erosion control, a seed source, and improved landscape aesthetics (Ambrose et al. 1983). Transplanting should be done in early spring (Plummer et al. 1968). Species that have been successfully transplanted include: antelope bitterbrush (Purshia tridentata), fourwing saltbush, black chokecherry (Prunus virginiana), American plum (Prunus americana), big sagebrush (Artemisia tridentata), black sagebrush (Artemisia nova), and rubber rabbitbrush (Chrysothamnus nauseosus).

Though expensive, transplanting can be more reliable because the field germination phase is by-passed (DePuit 1988). Transplanting may be useful in harsh environments such as extremely arid, steep, or erosive sites (DePuit 1988). It can also augment seeding by establishing species that:

1) Primarily reproduce by vegetative means.
2) Exhibit low, slow, or inconsistent germination
3) Exhibit poor seedling vigor immediately after germination.

Transplant survival may be enhanced by a number of husbandry practices (Yoakum et al. 1980; DePuit 1988):

1) Proper seedling acclimation and treatment improve initial survival under field conditions. Important considerations may include adequate seedling development and hardening prior to transplanting, transplanting during periods of dormancy or seasons of lower climatic stress, temporary irrigation, or transplanting into prepared microsites. Transplants must be kept moist until planted.
2) Occasionally, protection from browsing is required. Deterrents include fencing, chemical repellents, or most commonly, exclosures.
3) Sometimes interspecific competition must be reduced to assure seedling survival. Methods include transplanting to a site before it is seeded or treating the site, either mechanically or chemically, to inhibit other species.

Cuttings, layering, and suckers are appropriate methods for propagating transplants (Yoakum et al. 1980). Detailed instructions are available from most state agricultural experiment stations and horticultural textbooks.

Cuttings - a portion of a leaf, leaf-bud, stem, or root is removed from the parent plant and placed in a suitable rooting medium to form roots and shoots (Hartman and Kester 1975; Yoakum et al. 1980). Tree species do not generally root from cuttings, but some may be stimulated to form root primordia by girdling the shoot 4 to 8 weeks before cutting (Hare 1977). Many new

plants can be propagated in a limited space and for species that root readily, cuttings are inexpensive, rapid, and simple to propagate (Yoakum et al. 1980).

Yoakum et al. (1980) recommend consideration of the following when selecting cutting material:

1) Rooting ability varies greatly, even among individual plants. The literature may give an indication of the rooting ability of some wild plants or related cultural species.
2) Cuttings with the highest starch content are best suited for propagating. Starch content can be determined by immersing the ends of freshly cut stems in 0.2% iodine solution (potassium iodide) for 1 minute; the darkest stained cuttings have the highest starch content.
3) Avoid succulent, rapidly growing plants.
4) Cuttings from young plants generally root more readily than those from older plants. Juvenile growth can sometimes be induced in mature plants (Hartman and Kester 1975).
5) Other factors to be considered include:
   a) lateral vs terminal shoots - lateral shoots may produce horizontal spreading plants; terminal shoots may produce erect plants.
   b) flowering vs vegetative shoots.
   c) cuttings from different parts of the shoot.
   d) best time of year to take cuttings from specific plant species.

Layering - stimulates root development on a stem while it is still attached to the parent plant (Yoakum et al. 1980). A portion of a plant stem is covered with a rooting medium until it develops sufficient root mass. Disadvantages are that each plant requires individual attention and increased hand labor. Advantages of layering are that larger plants can sometimes be produced in a shorter time than starting with cuttings, and individuals with little plant propagation experience can use this technique.

Suckers - are shoots from adventitious root buds. Suckers are usually removed by digging down and cutting shoots from the parent plant in the dormant season (Yoakum et al. 1980). Where no roots are formed, suckers can be treated the same as cuttings.

Grafting - is a specialized technique of joining plant parts together so they unite and grow as one plant (Yoakum et al. 1980).

Vegetation diversity can also be increased by various sodding practices, which involve the excavation and deposition of plants and their intact root/soil masses (DePuit 1988). The most suitable species are shallow-rooting plants capable of forming a tight sod, such as rhizomatous or stoloniferous grasses, and species capable of vegetative reproduction or spreading. Sodding may have its greatest utility on steep slopes and drainages, where erosion control is needed, or on scattered, localized sites where islands of mature plants are desired to increase diversity and facilitate seed dispersal and colonization by soil microorganisms (DePuit 1988). Dryland sites receiving less than 41 cm of precipitation should not be sodded (SCS 1988). Sodding is not currently practiced in Wyoming. References include Sindelar (1973); Jensen and Sindelar (1979); Larson (1981); and McGinnies and Wilson (1982).

Shrub pads have been transplanted in Colorado (Carlson et al. 1982) and Wyoming to establish groups of mature shrubs and trees on mined lands. "Plugs" are another variant involving smaller groups of plants (Monsen 1979).

SUPPLEMENTAL HUSBANDRY PRACTICES

Irrigation

Mulching, surface modifications, and other practices are employed to conserve water, but sometimes temporary irrigation is also applied in arid regions. Like fertilization, irrigation is not recommended. Excessive or improperly applied irrigation can have adverse effects, including artificially high plant densities, shallow root distribution, and low diversity (DePuit et al. 1982). Irrigation can also result in domination by poorly adapted species in an arid climate. Irrigation reduces mortality during seedling emergence and establishment; however, when water is withdrawn and natural climatic vagaries stress the young plants, previous benefits of supplemental water disappear (Cook 1988). On arid sites, results usually consist of poor establishment for both watered and unwatered areas (Cook 1988). On semiarid sites (31 to 36 cm annual precipitation), plants receiving water for a year or two are higher producers and more dense for as many as 4 to 5 years, but after 8 to 10 years, there are often no discernable differences between irrigated and nonirrigated plants.

Although vegetation may establish more slowly without irrigation, it will later survive drought better without supplemental watering (Redente et al. 1980). Native grasses that may establish successfully without irrigation include western wheatgrass, streambank wheatgrass (Agropyron riparium), and other wheatgrasses (Redente et al. 1980).

Fertilization

Fertilization is not normally recommended for range seeding (U.S. SCS 1988). We agree and do not recommend fertilizing reclaimed mined lands. The purpose of fertilization is to improve plant growth and soil development. Its effectiveness generally increases with higher precipitation or irrigation. However, fertilization of reclaimed lands poses several problems. Continued fertilization may preclude development of a self-sustaining plant community. Also, high nutrient and water inputs may increase weed infestation, reduce vegetation diversity (DePuit and Coenenberg 1979; Redente and DePuit 1988), produce vigorous growth in annuals which cause them to crowd small seedlings of more desired species (Cook 1988), and in some cases, ultimately leads to nitrogen depression and vegetation retrogression (DePuit et al. 1978; Schafer et al. 1979). Individual range plants frequently respond differently to types and rates of fertilization (Doerr et al. 1984). Grasses can outcompete shrubs when fertilizer and irrigation are both applied (Redente et al. 1980; Koehler 1985). Fertilization can lead to decreased density, cover, and biomass of some forbs (Redente et al. 1980).

Nitrogen fertilization particularly favors cheatgrass and other annuals over seeded perennial grasses (Harris 1967).

LONG-TERM MAINTENANCE

Maintenance practices may be employed to ensure the reclaimed ecosystem develops toward desired conditions (DePuit 1988). DePuit (1982) defined three categories of specific practices:

1) Protective practices control deleterious influences

2) Corrective practices repair unsatisfactory results or damage.
3) Manipulative practices assist development toward objectives.

Maintenance practices that involve redisturbance will affect the bond period and, although feasible, may not be practiced because of the added time and expense.

Most management practices are based upon edaphic, hydrologic, and biologic manipulations. Unfortunately, they have not been extensively evaluated in the literature (DePuit 1988).

Protective practices can include controlling or eliminating overutilization by livestock, and large and small wildlife; insects; restricting vehicle access; etc.

Wildlife may be attracted to the reclamation site at the wrong time of year or too early in the process, too many animals may be attracted to a site, or unwanted and/or nuisance wildlife species may use the site (Green and Salter 1987).

To help reduce potential damage to revegetation by wildlife, Green and Salter (1987) recommend:

1) for mice, voles, and hares: reduce grasses and legumes in areas planted with tree seedlings; provide alternative foods in areas away from seedlings plantations; apply chemical repellents to seedlings to directly reduce girdling damage.
2) deer and elk (Cervus elaphus): fence areas to prevent access to woody plants; interplant unpalatable species and apply chemical repellents to palatable species to directly reduce browse use; provide alternative foods (hay, green feed, alfalfa pellets).

Corrective practices include treating persistent weed infestations with herbicides, prescribed burning, or mowing prior to seed maturation (DePuit 1982; Coenenberg 1982); and repairing rills and gullies. Partial revegetation failures can be treated by interseeding or transplanting (Brock 1982). Other maintenance practices include occasional light harrowing to alleviate soil crusting, and periodic stabilization (mulching, microimprinting, etc.) where erosion is a recurring problem (DePuit 1988).

Manipulative management can be conducted using some of the "corrective" practices listed above (DePuit 1988). Grazing management is another potential manipulation. Grazing can be regulated to alter plant species composition; increase volunteering by nonseeded species; improve plant production and vigor; improve vegetation diversity; and accelerate reduction and incorporation of plant litter into the soil (DePuit 1982).

GRASS AND FORB COMPONENT

Functions

As forage, grasses are most nutritious during spring and summer (Brown et al. 1986). Nutritional value declines after plant maturation. However, grass provides digestible energy in adequate quantities after maturation. Over winter, gestating herbivores require both grasses and shrubs - shrubs for the carotene, digestible protein, and phosphorus; and grasses for the digestible protein. The complementary qualities of these two life forms for herbivores demonstrates the importance of a diverse plant community.

Forbs are desirable, succulent foods in the spring and early summer; are usually very short-lived; weather quickly; and generally are unavailable by late summer (Brown et al. 1986).

Wildlife and livestock utilize forbs during the spring and summer growing periods. Forbs seldom cure well and generally weather and disintegrate quickly following maturing. They have been used sparingly or not at all on rangelands where precipitation is low and seedbed preparation is difficult. Two principal factors limiting the use of legumes in range seedings have been low persistence and bloat hazard (Heinrichs 1975).

Adapted legumes can increase total production when used with grasses (Yoakum et al. 1980). They also improve the forage nutritive value for many wildlife species. Soil nitrogen is increased through the action of associated nodule bacteria which converts free nitrogen from the air into available soil nitrogen.

Legumes are the most common group of nitrogen-fixing species and are included in almost every seed mix (Munshower 1994). Although native legumes fix smaller quantities of atmospheric nitrogen than most agronomic species, native legumes reproduce and perpetuate the species on the disturbance, whereas agronomic legumes are gradually displaced from the community by more aggressive plants.

Sainfoin (Onobrychis viciaefolia), cicer milkvetch (Astragalus cicer), falcatus milkvetch (Astragalus falcatus), and birdsfoot trefoil (Lotus corniculatus) are all nonbloating legumes. They show promise for seeding rangelands in selected situations in the western U.S. (Heinrichs 1975; Plummer et al. 1968; Townsend et al. 1975, Wilton et al. 1978).

General Planting Methods

Cool season grasses germinate and begin growth in early spring, often depleting the moisture available to warm season grasses during their critical germination and growth periods. To increase germination of warm season grasses, Long suggested two right-angle passes over the seed bed, planting half the total seeding rate on each pass with an eight-inch row spacing. The first pass would be perpendicular to the fall line, the second would be along the contour. The second pass would form ridges to help control erosion and should reduce the ridges of the first non-contour pass. Because of the spacing, a mosaic of seed combinations would occur. Half the grid would be sown with only warm season grasses, increasing their chance of survival. This has not yet been field-tested, but it was accepted by three regulatory agencies (the authors did not identify the agencies).

Warm-season grasses on the Northern Great Plains usually do better on rocky coarse-textured soils, hillslopes, or heavy clay soils where cool-season grasses compete less successfully (Munshower 1994). Because of mild slopes and uniform layers of topsoil found on coal minesoils, warm-season species have less chance of persisting in any great numbers with more competitive cool-season grasses.

Legume seed should be inoculated with the appropriate species of bacteria prior to seeding to ensure maximum nodulation and nitrogen fixation (Munshower 1994).

SHRUB COMPONENT

Trees, shrubs, and sub-shrubs are extremely important ecological components in the semi-arid and arid west, but they can be difficult to reestablish after drastic disturbances. Because of its importance to many wildlife species, big sagebrush is discussed later in this section. Other important shrub species are included in Appendix A.

Functions

Shrub functions include (McKell 1975; McArthur et al. 1978; Klemmedson 1979; Tessmann 1985; Brown et al. 1986):

1) Passerine nest sites
2) Cover and forage for upland game birds, small mammals, big game, and livestock
3) Snow accumulation sites which increase soil moisture
4) Moisture conservation through shading soil and reducing wind evaporation
5) Forage and cover above snow in severe winters
6) Increased wildlife diversity when shrubs are interspersed throughout a grassland
7) Drought tolerance, partly due to both extensive surface and deep root systems
8) Heat efficient photosynthetic pathway
9) Salt tolerance
10) Rapid regrowth after defoliation
11) Soil stabilization
12) Nutrient exchange with associated plants to help maintain ecosystem function
13) Aesthetic enhancement, create greater visual interest by increasing plant height diversity, patchiness, color, and associated wildlife.

Shrubs provide winter nutrition that is unavailable from most herbaceous vegetation (Brown et al. 1986). During winter, digestible protein (DP) is higher in shrubs than grasses (Cook 1972). Fourwing saltbush, winterfat, big sagebrush, and curlleaf mountain mahogany (Cercocarpus ledifolius) exceed DP upper ranges for deer and sheep. Black sagebrush and shadscale (Atriplex confertifolia) contain DP in the lower range (National Academy of Sciences 1964; Welch 1981).

Although grasses offer a higher total digestible nutrient (TDN) content than shrubs in winter, some evergreen shrubs are exceptions (Cook 1972). Curlleaf mahogany, big sagebrush, juniper (Juniperus spp.), and two grasses -- sand dropseed (Sporobolus cryptandrus) and western wheatgrass -- exceed deer and sheep TDN requirements in winter (Welch 1981).

Shrubs generally contain higher winter levels of phosphorus and carotene (a precursor of Vitamin A), than grasses (Cook 1972). Carotene deficiency would only be a problem for animals consuming large quantities of dormant grass. Most shrubs supply carotene at many times the level required by deer and sheep (Welch 1981). Calcium is not a problem in winter as most forages exceed dietary requirements (Welch 1981).

General Planting Methods

There are several recommendations for planting browse species. For successful direct seeding of shrubs, the competitive effects of concurrently seeded species and/or established species must be controlled (Skilbred 1990). The simplest method is seeding only shrub species into areas to create shrub mosaics. Another approach is to control interspecific competition by reducing the grass/forb portion of the seed mix to less than 50% of the total pounds of seed (Skilbred 1990). A third method involves seeding the shrubs alternately in strips with grass and forb seeds in one strip and shrub seeds in the other (Hubbard 1956; Plummer et al. 1968). A fourth method is two-pass seeding where shrubs are seeded first and grass/forbs are seeded next. Another approach is interseeding shrub seeds into previously established vegetation (mentioned

above under multiple stage seeding). Under this last approach, the established vegetation is scalped or plowed where the shrubs are to be planted to reduce competition.

Skilbred (1990) evaluated different seeding methods at a coal mine in east central Wyoming. Seedling establishment varied according to the seeding strategy. Broadcast seeding of shrub seeds yielded the highest numbers of shrub seedlings. Sagebrush seedling emergence is maximized at planting depths of 0.5 cm or less (Walton et al. 1984). Highest numbers of shrub seedlings were found on the shrub mosaic study site. Big sagebrush and winterfat were broadcast seeded (Brillion) and since herbaceous species were not seeded on those sites, the competition was minimal. Acceptable shrub seedling establishment resulted from the two-pass, strip seeding and interseeding techniques. Skilbred (1990) noted that although the planting procedure affected the number of shrub seedlings established, the soil temperature and water potential at the time of seed germination probably have a greater impact on sagebrush seedling establishment and survival.

In swales, along drainages, north facing slopes, and other well drained, moist sites, shrubs may have a competitive edge over grasses. Light-seeded native shrubs such as sagebrush and rabbitbrush should be broadcast seeded, whereas saltbush and winterfat will germinate well using either drill seeding or broadcasting methods (Tessmann 1982b).

Browse species that survive well from container or bare root stock in Wyoming are silver sagebrush (Artemisia cana), rubber rabbitbrush, Woods rose (Rosa woodsii), skunkbush sumac (Rhus trilobata), and snowberry (Symphoricarpos spp.); however, skunkbush sumac can be severely affected by drought (Booth and Schuman 1981; Clarke and DePuit 1981).

In the shadscale zone (or salt desert shrub) of southwestern Wyoming, it is particularly important to use native plants adapted to the particular site (Bleak et al. 1965). In this zone there are prolonged or severe droughts which inhibit seed germination. Low humidity, high evaporation, and high diurnal temperature fluctuations are also common, increasing the severity of the climate.

Note: the species of dominant pre-mine shrubs should be the primary shrub species used in reclamation; other shrub species that did not occur on the site should have minimal inclusion in revegetation.

Big Sagebrush

Big sagebrush is the most ecologically significant shrub in Wyoming coal regions. Subspecies include Wyoming big sagebrush (Artemisia tridentata wyomingensis); basin big sagebrush (A. t. tridentata); and mountain big sagebrush (A. t. vaseyana). Wyoming big sagebrush is preferred for reclamation.

For antelope and mule deer, the palatability is fair to good, particularly mountain and Wyoming subspecies (Wasser 1982). The basin subspecies contains significantly higher winter levels of crude protein than Wyoming and mountain subspecies (Welch and McArthur 1979). Big sagebrush is highly digestible to deer because monoterpenoid levels are reduced about 80 percent by the rumen (Welch and Pederson 1981).

Big sagebrush is extremely important to sage grouse for forage and cover year-round. To develop sage grouse habitat, shrubs should be planted in a mosaic of patches alternating with

grasses and forbs to create favorable interspersion of food and cover. Forbs are a major summer forage item for both broods and adults (Patterson 1952; Peterson 1970; Wallestad et al. 1975).

Proctor et al. (1983a, 1983b) recommended the following guidelines:

1) Sagebrush intermixed with forbs is utilized by sage grouse and other game and nongame wildlife.
2) Nesting areas should have a sagebrush canopy cover of 20 to 40 percent, and heights of 17 to 79 cm (Braun et al. 1977).
3) Open areas, 0.1 to 0.2 ha, surrounded by sagebrush, provide strutting grounds (Johnsgard 1973).
4) Less dense stands with lower canopy cover provide areas for rearing broods. Young broods use stands with average canopy cover of 14 percent (Martin 1970) and height of 23 to 38 cm (Johnsgard 1973).

The grass/forb area between sagebrush should be no wider than 30 m (Braun et al. 1977) and the patch of sagebrush should be no smaller than 30 m. Postovit (1981) observed sage grouse tend to remain within a few meters of sagebrush. A few sagebrush plants scattered in the grass/forb openings would provide islands of cover to increase sage grouse use. Autenrieth (1969) observed sage grouse foraging on forbs in 15 m-wide strips between sagebrush. Big sagebrush should also be planted along drainages and in strips that interconnect undisturbed areas as travel corridors and cover (Postovit 1981). Sage grouse avoid dense, monotypic stands, except during winter (Postovit 1981).

Optimum density of sagebrush canopy varies with age and sex of the birds. Areas with diversity in sagebrush density appear to be preferred. One recommendation is for a mosaic of areas with moderately dense (20 to 30 percent canopy coverage), moderately tall (25 to 50 cm) big sagebrush, with an understory of grasses and forbs for nesting. More open areas, 10 to 25 percent canopy coverage, containing a greater amount of forbs should be interspersed throughout (Klebenow 1969; Martin 1976; Braun et al. 1977). Important forbs are dandelion, common salsify, and prickly lettuce (Klebenow and Gray 1968; Peterson 1970; Wallestad 1975). Forbs are important during the summer as forage (Patterson 1952; Peterson 1970; Wallestad et al. 1975). Sagebrush and forbs planted in a mosaic or strips along drainages provide good brood-rearing habitat.

Dense sagebrush on south or west-facing slopes provides winter feeding sites for wildlife and protective cover which remain relatively free of snow (Rutherford and Snyder 1983). Snow fences or snow barriers concentrate snow and can be used at the top of gentle (less than 5 percent) south- or southeast-facing slopes to expose more sagebrush for critical winter habitat.

Big sagebrush also provides cover and food for small mammals (Johnson and Hansen 1969), and nest sites for sparrows such as Brewer's (Spizella breweri) and vesper (Pooecetes gramineus) (Best 1972).

Big sagebrush has been difficult to grow on drastically disturbed land for several reasons: it is a later seral stage species; it needs deeper (unrestricted), well-drained soils; it is often outcompeted by cool season grasses; there is not a large bank of viable seeds in the soil; the reclaimed topsoil lacks the necessary mycorrhizal associations; and it has highly specific germination requirements (McKell and Van Epps 1981; Young 1988). Wyoming big sagebrush can probably tolerate drier soils than basin big sagebrush (Barker and McKell 1986; Leonard et al. 1988). Wyoming big sagebrush and mountain big sagebrush are chiefly found on moderately deep soils (Miles and Leonard 1984).

Germination characteristics: flowering occurs in late September when soil profiles are often virtually completely free of moisture normally considered available for plant growth (Young 1988). Seed production per plant is highly variable. Only a tiny fraction of the previous year's seeds are viable, so germination is dependent on the present year's seed crop. Seeds of most collections will germinate as soon as they are collected, although some sources have afterripening requirements (McDonough and Harniss 1974).

Seeds that have a chance to become established seedlings germinate in late winter (Young 1988). Years may pass without a successful seedling becoming established in a stand. Establishment is directly related to the potential of the seedbed as defined by the number of sites with temperature and moisture relations capable of supporting germination.

Where studies have been made of progeny of isolated big sagebrush plants, the seedlings are distributed in an elliptical pattern reaching out from the shrub canopy in the lee of the prevailing winds. The dispersal pattern is usually oriented from the northeastern side of the shrub. The length of the colony is rarely more than a meter in length (Frischknecht and Bleak 1957), thus natural revegetation from surrounding sagebrush communities may take a long time.

Reclaimed soils are often uniform in depth, without the soil development and horizons found in undisturbed soils. Distribution of sagebrush habitats in southeast Oregon was statistically explained by soil texture, subhorizon sequence, rock fragment content, color, horizon thickness, ped (natural soil aggregate) size, and structure type, in that order of relative importance (Lentz 1984).

A variety of seeding techniques and surface treatments have been tried. Seed should be either hydroseeded or broadcast for best results. Competition from other species reduces shrub establishment, therefore, areas with the best potential for growth should be seeded with shrubs only. If shrubs are planted concurrently with grass, the shrub broadcast rate should be substantially increased, the grass drill rates reduced - warm season grasses at 1/2 rate, and the row spacing increased. To reduce competition, do not seed shrubs with cool season grasses. Plant sagebrush in the fall on well drained soils, along benches, drainages, and slight to moderate slopes. Areas with deeper, unobstructed soils are better for establishment.

Several mines have established isolated tracts of sagebrush growing at good densities. These include: Carter, Rawhide; Carter, Caballo; Kerr McGee, Jacobs Ranch; and ARCO, Black Thunder. NERCO, Dave Johnston has successful research plots.

Other Shrubs

Shrub species recommended for wildlife habitat reclamation include (Wyoming Game and Fish Department 1976):

1) serviceberry (Amelanchier spp.)
2) fringed sagewort (Artemisia frigida)
3) black sagebrush (A. nova)
4) birdsfoot sagewort (A. pedatifida)
5) true mountain mahogany (C. montanus)
6) curlleaf mountain mahogany (C. ledifolius)
7) Douglas rabbitbrush (Chrysothamnus viscidiflorus)
8) rubber rabbitbrush (C. nauseosus)
9) antelope bitterbrush (Purshia tridentata)

10) currant (Ribes spp.)
11) greasewood (Sarcobatus vermiculatus)

TREE COMPONENT

Functions

Trees form windbreaks and shelterbelts for wildlife and livestock; provide habitat for wildlife; can improve slope stability because of their extensive root systems; improve soil moisture conditions; cut wind velocity at the soil surface; and improve aesthetics.

General Planting Methods

Tree establishment can be difficult for a variety of reasons including (Jackson 1991): compacted soils after land is returned to AOC (Vogel and Gray 1987); competition from a dense growth of stabilizing grasses and legumes (Ashby et al. 1988; Davidson 1989); and mice and other rodents may be attracted to the site and damage seedlings (Ziemkiewicz et al. 1988). Trees should be planted only on sites that would naturally produce them (Brown et al. 1986), for example, concave slopes with increased moisture availability and riparian areas.

Trees on the Great Plains are usually planted as containerized or bareroot stock (Munshower 1994). Grasses and legumes compete with newly germinated tree seedlings. Establishment of trees could therefore be enhanced if the tree seeds or transplants are planted in strips or spots where forage seeds have not been sown, or by mechanically scalping vegetated areas within the forage stand (Lyle 1987). Soil moisture significantly affects seedling germination and establishment.

In Australia, a number of mines have collected seed of native tree species growing on the lease (Gordon and Hannan 1986). They have supplied the seeds to a nursery for raising the required tubed seedlings. When the seedlings are 6 to 9 months old, they are planted. Fencing may be required to protect young trees from large and small herbivores.

In many cases, creation and restoration projects have involved planting vegetation and not the creation of conditions suitable for the natural regeneration of riparian habitats (Carothers et al. 1990). Many planted riparian forests do not reproduce, thus their longevity is determined by the lifespan of individual trees. Information is needed on the most suitable watering regimes; suitable soil conditions for various tree species; long-term survival and growth rates; and effects of variable water table levels on planted trees.

Trees may be revegetated from nursery-grown rooted cuttings, dormant poles, seeds, and mature plant salvage (Carothers et al. 1990). Problems in establishing trees include: providing adequate water until the roots reach the water table;

Nursery-grown rooted cuttings of cottonwood and willow twigs can be planted in holes (preferably 38 cm in diameter) augered to the water table (Carothers et al. 1990). Small power augers are an effective planting method (Hoag 1992). Although irrigation is not recommended for revegetation in general, watering may be necessary for tree establishment until tree roots reach the water table. Amount and timing of watering depend on the soil, weather, and depth to the water table. Trees should be protected with wire fences for at least three years (Carlson et al. 1992), and some weeding may be necessary (Carothers et al. 1990).

Poles of cottonwood and willow are cut from dormant living trees (Carothers et al. 1990). Pole size ranges from 1.2 to 6 m in length (Carothers et al. 1990) and 4-13 cm in diameter (Carlson et al. 1992). The butt ends of larger dormant stock should be cut at a 45-degree angle and the growing end cut flat and treated with tree paint or other suitable sealant (Carlson et al. 1992). After the bases are scored (with an axe) and dipped in a fungicide/hormone solution, the poles are buried to the water table or wet soil. This procedure may also be used on non-dormant poles if all the leaves have been removed (Carothers et al. 1990).

Plantings of cottonwoods and willows should provide a minimum-width bank lining of 6 m (Carlson et al. 1992). A minimum of two parallel rows of mass plantings or pole plantings should be staggered or in a diamond pattern, with no breaks or gaps in the planting. Mass planting spacings range from 0.5-0.9 m; and pole plantings range from 0.6-1.8 m, depending on size of plant material. On the upper bank, spacings may be wider.

Dormant cuttings and poles must be planted to the summer water table depth (Carlson et al. 1992). Bareroot or container plants can be planted at or just above waterline, or on upper banks if weed competition is slight and moisture is adequate.

If bank sloughing is a potential problem, the cuttings should be planted at an angle nearly perpendicular to the natural angle of repose to minimize burial (Carlson et al. 1992).

Some mature trees can be salvaged from areas to be developed. Even if they do not survive, snags will result which are also important habitat features. The main disadvantage of this technique is the cost ($500 to $1000 per tree) (Carothers et al. 1990). Before digging, trees are pruned by more than half to reduce transpiration area (Carothers et al. 1990). A trench is dug along the sides of the tree and a box or bag is placed around the root ball. If the tree is not replanted right away, the tree is watered for about two weeks, after which the taproot is cut and a bottom is placed on the box. The tree is moved to a nursery where it can be kept (at expense) until it can be replanted at the reclaimed site. Planted trees must be watered for an indefinite period unless the water table is close to the surface and does not fluctuate greatly. Because the success of this technique is highly variable and expensive, it is recommended with caution. Cuttings and dormant poles are recommended for greater success in tree reestablishment.

Tree Species

Great Plains Cottonwood (Populus deltoides)

The cottonwood- to grassland sere is one of the dominant riparian seres in this region of the Northern Great Plains (Boggs and Weaver 1992). Cottonwoods provide thermal and hiding cover, (Hansen 1992); nest and perch sites; den sites; and future snags. It is woody species such as cottonwoods and willows that provide the greatest amount of streambank protection, not the herbaceous species (Hansen 1992).

The lack of cottonwood regeneration is a problem in some areas. Cottonwood trees evidently tap the water table, but as they die they are eventually replaced by species, such as silver sagebrush and western wheatgrass, which have lower transpiration requirements (Boggs and Weaver 1992). Approximately 50 percent of aboveground organic matter is lost when mature cottonwood are replaced by shrubs and grasses.

Great Plains cottonwood seedlings are typically established on alluvial mud flats. Characteristics of these areas are (Hansen 1992): soils are usually moist in the spring and early

summer and may remain saturated throughout the growing season; coarse-textured soils; and moderate stream gradients, and large amounts of coarse rock fragments in the soil profile. These provide conditions where highly aerated water can move rapidly.

To establish cottonwoods, dormant poles ranging to 6 m can be used to reach water tables, provide enough aboveground height to escape shading by weeds and browsing by large animals, and to resist burial by bank sloughing (Carlson et al. 1992). Pole plantings are less likely to wash out because of their greater structural attributes.

Hoag (1992) determined that long cuttings with large diameters planted into the midsummer water table gave the highest success rate.

Other Species

Primary riparian species are (Tessmann 1985): other cottonwoods (P. sargentii, and P. acuminata); willows (Salix amygdaloides, S. plantifolia, and S. drummondiana); box elder (Acer negundo); and green ash (Fraxinus pennsylvanica).

Other important trees in reclamation are juniper (Juniperus spp.) and ponderosa pine (Pinus ponderosa) (Wasser 1982).

WHY RANGE SEEDINGS FAIL

Many factors, acting alone or in combination can cause failures in range seeding. These factors include (Valentine 1989):

Germination of Seed
1) poor-quality seed (low germination, hard seed)
2) unfavorable temperature
3) insufficient soil moisture or competition for soil moisture
4) insufficient soil oxygen
5) high soil salinity
6) depredation by birds and rodents
7) insufficient soil coverage

Emergence of Seedlings
1) seeding too deep or too shallow
2) soil crusting
3) desiccation
4) wind and water erosion
5) rodent and insect damage
6) poor-quality seed (low vigor, shriveled, damaged)
7) high soil salinity
8) frost heaving

Seedling Establishment
1) drought
2) competition from weeds
3) competition of companion crops

4) soil infertility
5) insect, disease, and rodent damage
6) lack of inoculation of legumes
7) winter-killing and frost heaving
8) poor soil drainage and flooding
9) high temperatures (especially accompanying drought)
10) grazed before established
11) wind and water erosion (including wind shear)

Browse seedlings are generally more sensitive to frost, rodents, insects, and drought than grass seedlings because the growing points of browse seedlings are usually more exposed than in grasses (Valentine 1989). Spring frost damage has been particularly detrimental to bitterbrush. Legume seedlings are also more sensitive than grasses to frost.

VEGETATION PATTERNS TO PROMOTE WILDLIFE DIVERSITY

Optimal size and spacing of plant communities varies among wildlife species, and is influenced by both landforms and plant communities in adjacent areas (Green and Salter 1987).

The following are general guidelines for planting patterns to promote wildlife diversity (Hinkle et al. 1981):

1) Size of open areas seeded with grasses and forbs should be at least 0.2 ha.
2) Combine species with various growth forms, foliage, and fruit retention characteristics.
3) Provide multiple story windbreaks by planting a single row of shrubs next to two or three rows of trees in conducive locations such as drainages and bottomlands. Wide shelterbelts are better than narrow ones. Ground cover is important. Bird diversity increases when a well-developed shrub row is adjacent to an herbaceous understory.
   A good design might include ten rows, with dense shrubs planted on the outside to prevent snow from accumulating in the center of the shelterbelt where wildlife seek protection. Ideally, the center would be deciduous trees, then juniper and pine where birds and mammals could shelter during long winter weather periods. Use of windbreaks in the Northern Great Plains is significant for cottontail rabbit (Sylvilagus spp.), mourning dove (Zenaida macroura), gray partridge (Perdix perdix), sharp-tailed grouse (Pediocetes phasianellus), and off-ground nesting songbirds; incidental for wild turkey (Meleagris gallopavo), sage grouse, mule deer, and antelope; and limited for white-tailed deer (Odocoileus virginianus) (Podoll 1979).
4) Establish food and cover plots in open areas with clumped plantings of trees and shrubs. Areas around rock piles provide good microsites for planting trees and shrubs (some protection from herbivory may be necessary for young plants).
5) Linear plantings will provide travel lanes or corridors, cover, and food for many ground-dwelling birds and mammals. More sinuous rows decrease unnatural contrasts.
6) Food patches should be long and narrow so open areas are closer to cover than if the patch were round. These patches should be between 0.5 and 0.2 ha, with a minimum of one patch per 16 ha.
7) Plant shrubs in open areas between forested or cottonwood-riparian areas.

8) In shrub-dominated habitats, plant shrubs with the tallest mature heights in central, irregularly-shaped cores with shorter shrubs, grasses, and forbs blending gradually into surrounding areas.

Green and Salter (1987) recommend the following for establishing plant communities:

1) shrub clusters - provide core areas for shrubland reclamation. Concentrate shrub seedlings, bare root cuttings, and seeds in discrete units at least 0.5 ha. Avoid planting grasses and legumes within the clump to reduce competition. Protect plantings from wind in exposed areas with snow fences, rock or soil berms, brush piles, or deadfall.

2) topsoil islands - provide a thick, high quality growth medium for woody vegetation in areas with limited topsoil. These islands should be 0.5 ha or larger with 35-40 cm of topsoil. Between topsoil islands, plant grasses, legumes, and/or other forbs.

3) hedgerows - provide visual cover, travel corridors, and reduced wind exposure. Wide, multirow shelterbelts with 10-15 rows of trees and shrubs are better than single row plantings. Plant tall-growing coniferous and deciduous trees in the central portion of the hedgerow, with sequential rows of small trees, tall shrubs, low shrubs, and tall groundcover on either side of the central core. Spacing of plants varies with species - smaller plants are planted every 46 to 60 cm in rows 0.9 to 1.2 m apart; larger plants are planted every 2.4 to 3.7 m in rows about 2.4 to 3.0 m apart (Yoakum et al. 1980). Hedgerows 4.6 to 6.1 m wide are adequate for most wildlife species. Row length will vary, depending on wildlife needs and available space. Irregular rows with a random mix of more than one species are preferable (Green and Salter 1987). Where there are strong prevailing winds, shape the hedgerow in an L, U, or E-shape for increased wildlife protection.

   (An interesting suggestion by Yoakum et al. (1980) is to line or stagger fence posts about every 6.1 m down a strip where a hedgerow is desired. Wire or twine is strung between posts for a bird perch, and the bird droppings, laden with seeds, will "plant" the seedbed. They did not mention if this would be successful in the arid or semi-arid west.)

   Location (Yoakum et al. 1980) - low, woody vegetation can be planted along fence rows, in gullies, and along streams or around ponds, springs, food patches, and breeding grounds. One strip to each 50 to 62 ha in open country appears adequate.

4) transplanting - provides immediate cover on a site and a new localized source of seed material for invasion of native vegetation. Clumps of native trees and shrubs from adjacent areas can be transplanted with tree spades or front end loaders. Transplants should be placed in protected areas with damp to moist soils. The soil around the root ball must be well packed and clump edges should be sealed to prevent drying. Shrubs and trees less than 2 m high will be more likely to survive transplanting.

5) natural vegetation island preservation - provides immediate cover and food for wildlife and provides a seed and plant stock source for invasion into reclaimed areas. Leave fingers of natural cover along edges of development sites. If island preservation is possible during mine development and operation, they should be at least 0.5 ha, preferably along travel corridors, around important use sites, or adjacent to streams and waterbodies.

SUGGESTED REFERENCES

Suggested texts for selecting plant species used in western reclamation include: Soil Conservation Service (1988) Plant Materials Handbook; Hardy BBT Limited (1989) Manual of Plant Species Suitability for Reclamation in Alberta; Munshower (1991) Perennial Grasses for Revegetation of Disturbed Lands in the Northern Great Plains and the Intermountain Region and Forbs, Shrubs, and Trees for Revegetation in the Northern Great Plains and Adjacent Areas; Hafenrichter et al. (1968) Grasses and Legumes for Soil Conservation in the Pacific Northwest and Great Basin States; McAtee (1941) Plants Useful in Upland Wildlife Management.

When collecting native seed, Yoakum et al. (1980) suggest: Collecting and Handling of Seeds of Wild Plants (Mirov and Kraebel 1939) and Seeds of Woody Plants in the United States (U.S. Forest Service 1974).

Reclamation and Vegetative Restoration of Problem Soils and Disturbed Lands by Brown et al. (1986) provides useful information.